An *Ex-ante* Economic Evaluation of Patented Rootstocks for Apple Producers in New York State

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Lingyi (Moira) Li

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ABSTRACT

The establishment of the US public research system plays an important role in accelerating the development of the US agricultural economy. However, according to the technology treadmill theory, progress induced by advanced technologies have placed pressure on farmers to exit the industry. These farmers are potential clients and major political voices for public research sector. Lacking political support, the public research sector faces the severe challenge of covering its budgets. The introduction of the Bayh-Dole Act, by permitting public entities to charge for developed technology, offers them the opportunity to generate income from the private sector. Meanwhile, this lack of funding is unable to impede the pace of the public research sector to develop innovative biological technologies. This is due to the gap which has been caused by the private sector in its focus on inventing technology which caters to market demand. Moreover, the increasingly severe environmental challenges motivate a need for adaptive technologies.

The Geneva apple rootstock that is the focus of this thesis, is one of the innovative biological technologies invented by the public research system. It is challenged by a lack of public funding as it aims to address various plant diseases exacerbated by dramatic global climate change. The goal of this thesis is to complete an *ex-ante* economic evaluation of adopting Geneva apple rootstocks. In order to do this, we review the literature evaluating the technology adoption process and methodologies in conducting *ex-ante* analysis and introduce expected utility theory to quantify the adoption decision results. Our results show yield and location play important roles in determining accumulated net present value. Geneva apple rootstocks improve the accumulated net present values by increasing yields. As for risk analysis, constant relative risk aversion function is appropriate to utilize in the long-term commitment perennial fruit industry. The Geneva rootstock generates a higher certainty equivalent than current rootstock infected by the plant disease, fire blight. Its estimated investment value ranges from $7.35 to $42.52 per tree as the probability of fire blight increases.

BIOGRAPHICAL SKETCH

Lingyi Li is a second-year graduate student at Cornell University's Charles H. Dyson School of Applied Economics and Management, where her research concentration is agricultural economics.

Between her school years at Cornell, Li works with Professor Rickard as a research assistant, where she gained experiences on data analysis and conducting economic evaluation of technology adoption.

Born and raised in Chongqing, China, Li graduated from China Agricultural University and Purdue University in 2017 with major in Agricultural Economics and minor in Statistics.

This thesis is dedicated to Professor Bradley J. Rickard, my mentor in graduate school.

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Chapter 1 Introduction

1.1 United States Institutions for Research: Policy, History and Challenges

Since the provision for protecting intellectual property in the Constitution of the United States in 1789, private individuals and firms were motivated to invent advanced technology. But the limitations of developing technology were gradually exposed: almost all early innovations were mechanical field tools. This was mainly due to early patent laws that did not protect biological technologies, as the creation of plant and animal inventions was difficult, and agricultural technology was considered specific to each farmer's technique and therefore did not replicate on a massive scale (Huffman, 2008). The Patent Office initially recognized the problem regarding the lack of advanced technology that constrained the development of an agricultural-based economy. Consequently, the Patent Office engaged in promoting public agricultural research. As a precursor to agricultural research and development, the Patent Office and a group of agricultural lobbyists acted as a spur to establish the United States Department of Agriculture (USDA) in 1862.

In addition, in the same year, the passage of Morrill Act broke traditional education standards, by training college students to apply science in real life. The act constructed colleges of agriculture that have played an important role in educating intellectuals working in agriculture and spreading advanced knowledge. Moreover, the enthusiasm for developing agricultural innovations was unprecedented among agricultural societies during the 1800s. They offered cash prizes for the best inventions, constructed libraries and bought land for experimental purposes. The atmosphere they created built fundamental interconnections between farmers, extension services, and research institutions, which induced the passage of the Hatch Act in 1887. The Hatch Act was also illuminated by German advancements in laboratory-based science and constructed the state agricultural experiment stations (SAES). The following formal establishment of the cooperative extension service in 1914 by the Smith-Lever Act finalized the creation of the US agricultural institutions for research, the USDA-SAES system. This system is guided by the USDA and responsible for organizing research programs and collecting agricultural data. It includes land-grant colleges implementing field trials in the SAES, and the extension service connecting the relationship between local researchers and farmers, working in disseminating innovative knowledge and stimulating advanced technology adoption.

The inventive research programs, introductions of new technology, education for professions and farmers promoted by USDA-SAES system have become a primary source of US agricultural productivity gain. The increasing speed of real agricultural output growth was 1.61 percent per year in the 20th century. The percentage of farmers accounting for total US labor changed from 64% in 1850 to 2.6% in 1990 (Bellis, 2018). However, the rapid development of US agriculture brings various challenges to the current public research system. One problem is caused by agricultural structural change that is the decreasing number of farmers. This is an inevitable tendency based on the technology treadmill theory–the innovation of labor-saving technology benefits initial adopters and the farm product demand inelasticity reduces the total revenue as outputs increase. This scenario leads non-adopters or lagged adopters to be squeezed out of the industry. Many previous farmers became lagged adopters and as a result exited farming. At the same time, they were also the potential target clients for public research sector because of large production scale and major agricultural income. Therefore, the decreasing number of farmers reduces customers for public sector. Moreover, the public research system has long relied on political support from farmers. Tracing back through history, political lobbying from agricultural societies encouraged establishments of the USDA-SAES system, but now the public support is decreasing as there is a diminishing number of professional farmers. Another challenge for the public research system is its disadvantaged position in biotechnology development compared with private research sectors (Huffman, 2008). The representative technology in the biotechnology field is the genetically modified crop product that is currently only innovated by private-sector firms. In fact, land-grant colleges of agriculture have developed "pre-invention science" capacity. However, they are still unable to compete with private multinational firms because of their far smaller R&D budgets that limits the ability of public research sector to develop and market new products. Thus, the fall-behind place of the public research system in biotech innovation is not unexpected.

As more and more researchers from the public research system have recognized these challenges (Debertin, 1997; Huffman, 2008; Rickard, 2016), there are discussions about alternative R&D funding and strengthening development of the second-generation biotechnology. The passage of the Bayh-Dole Act in 1980 ended the requirement that land-grant colleges had to share licensing revenue coming from public research program with the government. This gradually changed incentives with regard to technology invention in USDA-SAES system, enabling them to generate income from patent licensing with private firms. The second suggestion is about the second-generation biotechnologies which are aimed to improve food quality comparing with the first-generation biotechnology which focused on increasing crop yields (Huffman, 2008). As the intense development of industrialized society, highly-educated and affluent consumers now pay more attention to healthier diets and ecosystem-friendly agricultural products (Dimitri, 2005). It may provide new chance for public research system to innovate the second-generation biotechnology with consumer-quality enhancement, such as low pesticide residue and higher food quality.

1.2 Challenges and Opportunities for Public Plant Breeding Programs

Plant breeding is a core responsibility of the public research system, and it plays an important role in developing new cultivars, meeting USDA's strategic goals in achieving agricultural sustainability and improving people's accesses to nutritious food. There are five public research agencies taking part in plant breeding programs: Agricultural Research Services (ARS), Forest Services (FS), and Natural Resource Conservation Service (NRCS) conduct plant breeding research. The National Institute of Food and Agriculture (NIFA) is responsible for offering public funding. The Economic Research Service (ERS) evaluates economic impacts of research. The research in this thesis is related to the ARS that is prominent in achieving transformation of non-adapted genetic materials into utilizable forms. It incorporates with its subordinate organization, the National Plant Germplasm System (NPGS) whose priority is to conserve plant genetic resources and databases, has succeeded in assisting breeders to cultivate advanced breeding crops (USDA, 2015).

Advanced inventions always come with various challenges. Some challenges facing the plant breeding field derives from the external environment, such as climate change, globalization with consistent immigration of weeds, diseases and insects, which exacerbate the difficulty of plant breeding, and at the same time, increase the need to develop adaptive cultivars. Also, taxpayers always question the worth of public research funding, which is aggravated when comparing with more successful research results accomplished by private research sectors. But economic analysis points out that private sector underinvests in many areas of agricultural research (Huffman, 2008; USDA, 2015). Private firms are usually not willing to commit to long-term exploratory research and absorb results that come slowly, which are often common in plant breeding research. On the other side, plant breeding, as a tool for technology inventions, create opportunities in rising public interests in improved food quality, increased nutritional value and conserving ecosystems. Therefore, it is necessary to conduct public research that requires a longer commitment. However, the US government still plans to reduce their budget in the public research sector (Tulsi, 2018). Therefore, more and more public plant breeding programs seek collaborations with end users via patent licensing in order to earn revenue. Typical examples in the plant breeding field are commercialization and licensing of apple cultivars, such as the University of Minnesota licenses SweeTango to farmers, and Cornell University licenses Geneva apple rootstocks to nurseries.

The Geneva Apple Rootstock Breeding Program that this thesis focuses on is under USDA-ARS guidance. It utilizes plant genetic data from NPGS and is conducted by scientists from Cornell University. This program faces the same challenges and opportunities with less public funding to develop quality-enhancing cultivars. Its invented new technology, Geneva apple rootstocks, aims to help apple farmers resist various diseases, improve yields and fruit quality. Since the research data is from New York State field trial, this thesis mainly focuses on the New York State apple industry, but the methods can be applied to other perennial fruit crops, and the conclusions are meaningful to other states.

1.3 New York State Apple Industry: Challenges and Opportunities

New York State is the second largest apple producing state in the United States; produced nearly 1.2 billion pounds of apples that were valued at around $317 million in 2016. The direct overall economic value to the whole state economy is $397.9 million in gross domestic product. There are 47,148 acres apple production in the New York State. The six major production districts are Champlain Valley, Eastern Hudson Valley, Western Hudson Valley, Central District, Lake Country, and Niagara Frontier with 1,365 farms. Although, similar to other agricultural sectors, the number of bearing acres and farms in the apple industry has declined since 1997, the apple production has trended upward over past 35 years, which is likely to be explained by the evident shift to innovative production system with higher density plantings (Schmit, 2018).

Even though the apple industry generates large economic benefits to New York State, there are problems facing by apple farmers that are worthwhile to address for sustaining this contribution in agricultural gross domestic product. One of the biggest challenges facing the New York apple industry is fire blight. Fire blight is a destructive bacterial disease that resulted in removal of 240 hectares of apple orchard and $42 million economic loss in Michigan State in 2000, and the estimated annual fire blight loss and disease control are over $100 million in the United States (Norelli, 2003). Fire blight occurs at distinct stages of tree growth and infects diverse parts of apple trees, such as, fruit, blossom, shoot, and rootstock. Among all plant organs, it is believed that rootstock is the key avenue of infection for the reason that fire blight bacteria moves downward from blossom and shoot into the rootstock to multiply and cause final infection (Norelli, 2000). Hence, studying the mechanism of how fire blight infects rootstocks and inventing alternative rootstocks are necessary to resist fire blight.

In addition, severity of fire blight infection does not only depend on the tree itself, but also is influenced by external environmental factors. Climate change may aggravate the vulnerabilities for fruit farming in the Northeastern United States by increasing frequencies of a wet spring (Figure 1-1) and more dramatic meteorological conditions (Figure 1-2) (Kunkel, 2013; Wolfe, 2018). Besides, warm wet spring and extreme weather events, like hail and wind damages are important inducers of fire blight incidence (Koski, 2009). Moreover, studying impacts of climate change on prevalent plant diseases, like fire blight, is a worthwhile research topic. An assessment in New Zealand has found climate change increases with temperature and precipitation, and this leads to higher level of fire blight (Coakley, 1999). Also, according to research conducted in Switzerland, the level of fire blight expanded from 1995 to 2007 (Figure 1-3) and obtained an unprecedented level because of humid spring in 2007 (Pautasso, 2012). Therefore, the fact that global climate change exacerbates the spread of fire blight, increasingly grievous local environment and severe worldwide examples should admonish fruit farmers in New York State to apply appropriate technology to prevent this disease.

Another exterior factor of evoking fire blight is present transformation of planting system from low-density orchard (around 162 trees/acre) to high-density orchard (around 607 trees/acre to 2400 trees/acre) in the apple industry (Robinson, 2008). That leads to substantial usages of dwarfing rootstocks, such as M9, M26 that are susceptible to fire blight (Norelli, 2000). Although, according to National Agricultural Statistics Service, the apple tree density has risen in New York State, increasing 24% from 223 trees per acre in 2006 to 277 trees per acre in 2011, tremendous researches manifest the economic efficiency of high-density orchard (Weber, 2001; Robinson, 2008; Lordan, 2018). Furthermore, scientists and extension coordinators have been promoting high-density apple planting technology over 40 years. Additionally, the largest apple producing state in the United States, Washington State, increased tree density from 494 trees per acre in 1991 to 921 trees per acre in 2010, among all trees that farmers use, about 50% are developed from dwarfing rootstocks (Knopf, 2010). As a result, the conversion from low-density to high-density farming is an irresistible tendency with an inherent problem that is the current fire-blight susceptible dwarfing rootstock. It threatens the sustainable development of apple orchards in New York State.

The rising frequency of extreme weather events and evolution of planting system technology increase the probability of fire blight infection and affect New York State apple production. In addition, the growing consumer demand for popular apple cultivars brings challenges but also opportunities to northeastern fruit producers. Based on the New York apple industry report in 2011, Gala is listed in the top ten varieties in New York State, Fuji is in the top three most popular varieties in the US. According to Fruit Growers News (Shanker, 2018), the production of the other popular cultivar Honeycrisp has doubled over the last four years, becoming the fifth most-grown variety in the US. At the same time, these recently successful apple cultivars, such as Honeycrisp, Gala, Fuji are much more susceptible to fire blight than traditional varieties, like McIntosh (Norelli, 2003). Furthermore, Honeycrisp induces a concern for Northeastern growers to compete with their massive, climatically advantaged competitors on the West Coast, due to it is vulnerable to many diseases under extreme weather. However, the price of Honeycrisp can be over twice as high as the price of Delicious (Gallardo, 2015), indicating its great economic attraction for fruit producers.

1.4 Geneva Apple Rootstocks: Research Program and Adoption Process

Given current concerns about fire blight and the demand for improved quality traits among consumers, present popular rootstocks, such as M9, M26 developed by England's East Malling Research Station since 1917, are susceptible to fire blight.

Another rootstock, B9 bred in the Soviet Union, is not ideal for current high-density planting systems. Thus, a new technology, Geneva apple rootstock have been introduced by Cornell University and USDA-ARS Apple Rootstock Breeding Program, and it has greater resistance to fire blight, crown and root rots, bitter pit, replant disease complex and woolly apple aphid compared with current common rootstocks. Therefore, adopting this innovative rootstock may help solve fire blight and improve yield efficiency (Fazio, 2013). Also, Geneva rootstocks have better performance with Honeycrisp (Robinson, 2011). However, the technology adoption is a long process requiring lots of field trials and extensive cooperation between farmers, extension workers and scientists.

The adoption process of apple rootstocks generally includes three stages: field trials, commercially releases to licensed nurseries and final adoption by apple producers. As compared with current common rootstocks, M9 that had been prevalent since 1940s, Geneva rootstocks is still a quite new technology in plant breeding field. Therefore, the present adoption of this innovative technology is still processing in the first two stages.

The initial phase of field experiments have taken tremendous time and efforts across North America and other parts of the world, because substantial combinations of local environments, rootstocks and apple varieties are waiting to be assessed. The schedule for building field trials includes 3 to 4 years to plan and establish trial, over 10 years to collect data and publish reports (Perry, 2002). Lots of research about evaluating the field performance of Geneva rootstocks have been conducted by NC-140, a regional research project designed to enhance sustainable practices in fruit production within the North

Central Region. The preliminary report of NC-140 can be traced back to 2002 when results from several trials in Michigan, Massachusetts, and New Jersey in 1992 to 1999 were available. In this initial report, scientists only had enough experience with one Geneva rootstock, G30, and made limited commercial recommendations on G30. The next report of NC-140 were published in 2003 and 2004 when results from 24 trials across North America were available. The broad geographical distributions of experimental trials comprises Southern region of the US (Georgia, Tennessee, West Virginia, Kentucky, Arkansas), Midwestern region of the US (South Dakota, Illinois, Indiana, Michigan, Missouri, Iowa, Minnesota), Northeastern region of the US (Maine, New York, Vermont, Pennsylvania), Western region of the US (Washington, California, Colorado, Oregon, Utah), and Eastern region of the Canada (Nova Scotia, Ontario, Quebec) (Robinson, 2003). In the following years, much research about evaluating specific elite Geneva rootstocks, and its performances in several locations with certain popular cultivars were published (Domoto, 2002; Autio, 2007; Robinson, 2011; Fuller, 2011).

The second stage of adoption for Geneva rootstocks started since 1991 when the first Geneva rootstock G65 was released for commercialization. Geneva rootstocks G30, G11, G16, G202, and G935 were then released in 1994, 1997, 1998, 2002 and 2004 (Robinson, 2003). Also, based on a great amount of performance evaluations from the first trial stage, another commercial releasing report (Robinson, 2004) was issued offering planting recommendations for seven introduced rootstocks (G65, G16, G41, G11, G202, G30, G935). This report indicated all of them were fire blight resistance and had potential commercial successes if nurseries and apple growers comprehend their strengths and deficiencies before adoption. After consistent introductions and productions in several years, a new review of summarizing adoption process reported estimated rootstocks productions in 2013. During these years, more genotypes of rootstocks have been tested and commercially released, such as G214, G969, G890. Rootstocks with fire blight resistant and good nursery characteristics, such as G11, G41, G935, G202 were approximated to increase total production from 1,850,000 liners to 2,750,000 liners in 2013. The extremely dwarfing, virus-susceptible rootstocks or rootstocks that are difficult to handle in the nursery were in limited propagation at about 100,000 liners per year, such as G65, G30 and G210 (Fazio, 2013). In 2015, a report provided the results of growing weak cultivar Honeycrisp on Geneva rootstocks, indicating weak cultivars growing on some Geneva rootstocks have less biennial bearing tendency. It also reports the new released Geneva rootstock G814 has the highest cumulative yield for Honeycrisp.

Furthermore, there is evidence of issues related to graft unions of Geneva rootstocks, such as G41 and G935, which are brittle varieties when propagating in nurseries. Research collaborating with Utah State University is evaluating several growth regulators to stimulate stronger graft unions. For rootstock production, it is estimated that 8.5 million Geneva rootstocks were produced in 2014 in 15 officially licensed producers located in Washington State (Willow Drive Nursery, Cameron Nursery, Gold Crown Nursery, VanWell Nursery, Helios Nursery), Oregon State (Willamette Nursery, Treco Nursery, Kit Johnston Farms, Copenhaven Nursery, KCK Farms, North

American Plants), California State (ProTree Nursery), Ontario in Canada (Mori Nursery), and Chihuahua in Mexico (Viveros Sacramento, Viveros Casas Grandes) (Robinson, 2015).

There is no research that directly examines the final adoption of Geneva rootstocks in commercial apple farms as it is still a relatively new technology. However, on the basis of reports from Good Fruit Grower (O'Brien, 2014), fire blight-resistant G11 and G41 are in big demand: in 2014, about 1 in 5 of the new trees shipped from nurseries to growers (about 2.4 million trees) is on Geneva rootstocks. Although, Geneva rootstock is popular because of fire blight resistance, it still faces several constraints. Fortunately, another report from Good Fruit Grower (Courtney, 2018) showed Van Well Nursery and others were having higher success rates with G41 propagation, and managers from these nurseries agreed there are learning curves on G41 and the series of Geneva rootstocks released in the past decades.

1.5 Research Question

Scientists have generated a great amount of agronomic analysis of the performance of Geneva apple rootstocks. Farmers and other participators in the technology adoption process are interested in a complete economic evaluation of the Geneva apple rootstocks over the 20-year life of an orchard. This thesis examines the economic impacts of adopting the Geneva apple rootstocks by comparing them to current popular rootstocks. It evaluates changes in the levels of yield, quality, and price, generates accumulated net present values and certainty equivalents in different probabilities of fire blight. The accumulated net present value framework estimates the expected monetary results of adopting this new technology. Moreover, the certainty equivalent results quantify the investment value of the Geneva apple rootstocks by incorporating farmers' risk aversions.

1.6 Thesis Outline

This thesis begins with an overview of US public research sectors related to plant breeding, introduces data about the New York State apple industry and the existing technology, Geneva apple rootstocks. Chapter 2 reviews the relevant literature on economic research of agricultural technology adoption, methodologies about ex-ante analysis of agricultural technology adoption and expected utility functions to evaluate farmers' adoption decisions. Furthermore, I identify the gap between the current literature and the present situation. Chapter 3 introduces the data used in this thesis and how these data were collected. In Chapter 4, a farm-level simulation model and financial model are constructed to estimate the monetary results of adopting different technologies, and an expected utility function is utilized to quantify the investment value. Chapter 5 presents assumptions for the models and summarizes my parameterization results. Chapter 6 concludes with implications for private investment in the Geneva apple rootstocks and provides some direction for future research.

FIGURE

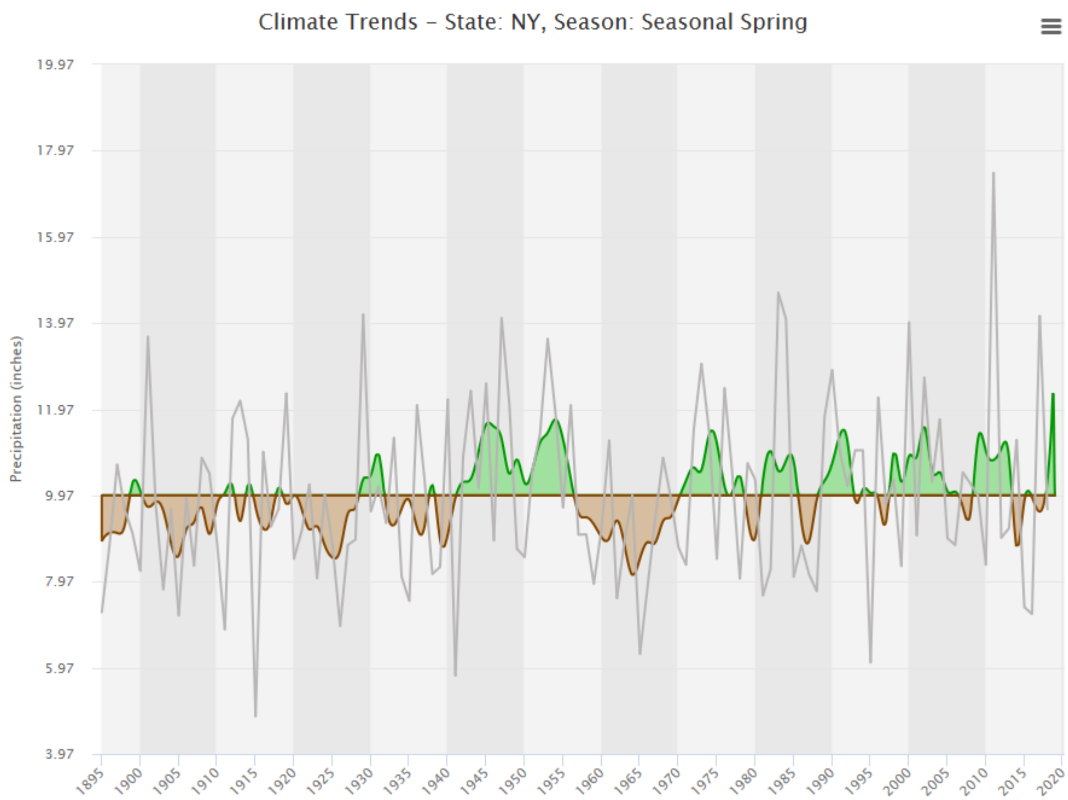

Figure 1-1 New York State Seasonal Spring Climate Trends

Note: This chart is from “NOAA Technical Report NESDIS 142-1” (2013). It provides a comparative spring season analysis for precipitation in New York State. Long term averages are taken from NCDC's annual rainfall datasets. The 5-year moving averages of annual values are plotted in comparison to the long-term average as upper or bottom curves for precipitation, an upper curve indicates a period that is wetter than the historical average, while a bottom curve is drier than the historical average. Based on this chart, the frequency of precipitation in spring is greater after 1995 than in previous years, indicated by more repeated green areas after 1995.

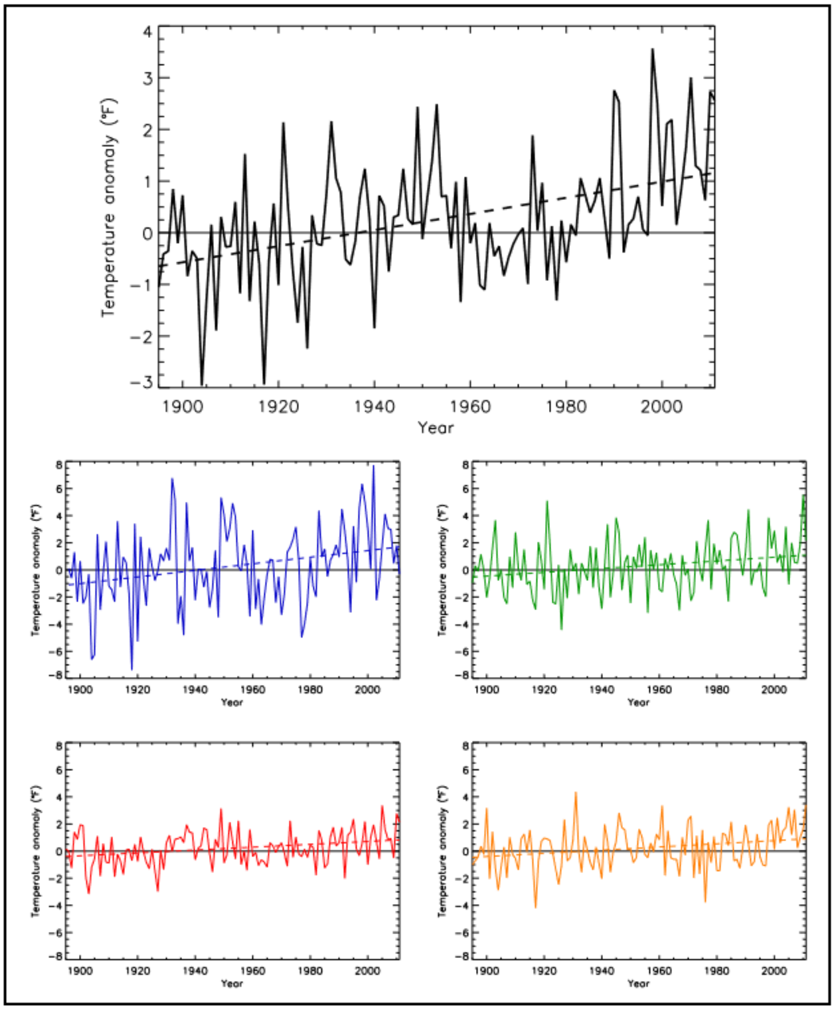

Figure 1-2 Northeast US abnormal temperature tendency

Note: This graph is from "NOAA Technical Report NESDIS 142-1" (2013), which shows temperature anomaly (deviations from the 1901-1960 average) for annual (black), winter (blue), spring (green), summer (red), and fall (orange), for the Northeast U.S. Dashed lines indicate the best fit by minimizing the chi-square error statistic. Based on a new gridded version of COOP data from the National Climatic Data Center, the

CDDv2 data set. According to this graph, trends are upward and statistically significant annually and for all seasons, which indicates weather are more extreme.

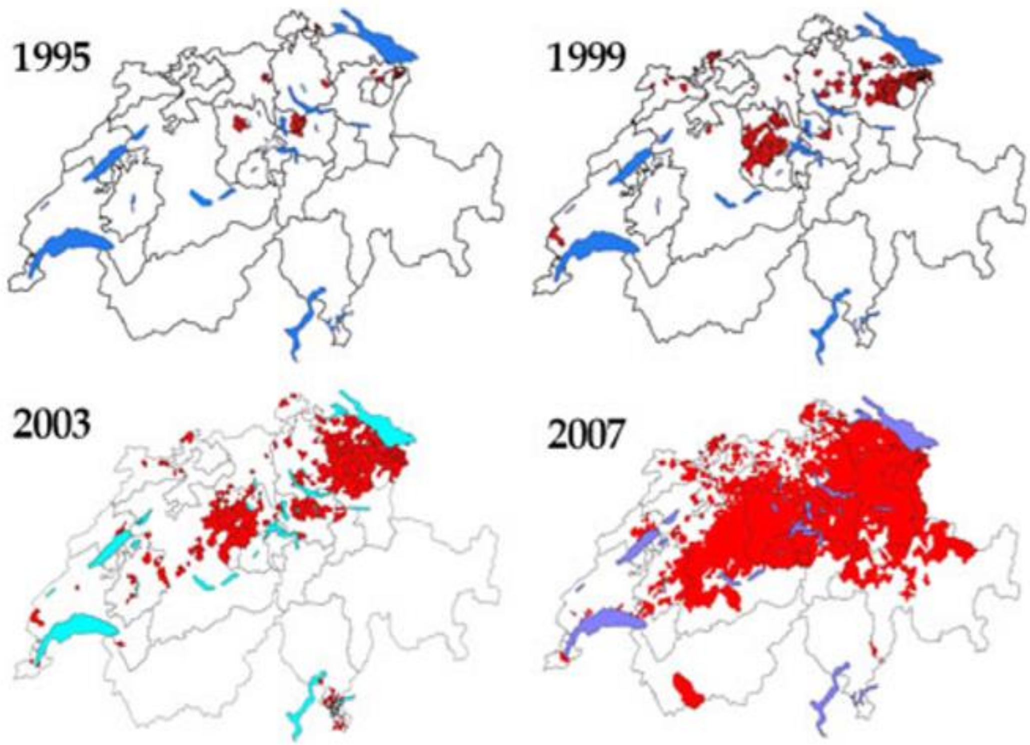

Figure 1-3 Growing level of fire blight from 1995 to 2007 in Switzerland

Note: This graph is from "Impacts of climate change on plant diseases—opinions and trends", (2012) which shows growing level of fire blight from 1995 to 2007 in Switzerland. Fire blight is especially favored by humid spring in 2007, reached unprecedented levels indicated by larger red areas then other years.

Chapter 2 Literature review

2.1 An Overview of Economic Research on Agricultural Technology Adoption

For decades, much research have tried to explain the process of agricultural technology adoption and conduct innovation impact analysis. Motivations to understand farmer's adoption decisions and reasons to use certain technologies have been studied to better understand the adoption process and to assess the impact of agricultural research.

Griliches (1957) studied the technology adoption process by focusing on the three stages of hybrid seed corn adoption, using logistic growth functions to generate three parameters: origins, slopes, and ceilings. Lindner (1982) separated the adoption process into three steps: awareness, try out of technology, and continued adoption. Lambrecht (2004) established a model to explore the three steps and pointed out different determinants of specific steps. As for the awareness step, which is defined during the period from availability of innovation to the awareness by users, initial information and farmers are crucial in the discovery stage. The quality of information depends on the time of spreading. In the research conducted by Kabunga (2012), awareness did not significantly affect adoption rate as the technology had been introduced ten years previously. Also, the information is determined by the location, like places where the intensity of extension program is different or close to neighborhoods that have already adopted the technology. The characteristics of accepters of information, farmers, are also important, such as their willingness to learn new techniques, their education levels, risk aversion levels, and social network conditions.

The try-out step is defined from recognizing the technology to first utilization; the information about technology attributes and market situations from *ex-ante* test can help farmers decide realistic expected returns. Another factor, farmer's adopting ability, exhibited by size of land, labor and capital intensity may constrain this process. As for the continued adoption step, the major determinant is the on-farm information, focusing on the profitability of new technology. That may be affected by information from the previous two steps. For example, if farmers are better informed, they may generate higher returns, and are more likely to continue adopting. If the realized profit is far below expected profit, farmers may abandon technology even if there is a positive return. Furthermore, the net return of an agricultural technology depends on external agro-ecological factors, such as soil and precipitation. Studies show the higher degree of lack of information under different biophysical conditions, the more determinant the external factors are in farmers' technology adoption decisions.

The three-step concept and the key factor of information also extend to technology adoption in the apple industry as it related to the rootstock selections. Another study identifying obstacles of adoption of Integrated Pest Management (McDonald, 1994) also suggested farmer's perception of economic viability affected the technology adoption. Therefore, based on the previous literature, the unimpeded diffusion of information and reliable expected return concluded from an *ex-ante* economic analysis can play an important role in the farmer's adoption decision, which also justifies the worth of extensive trial field experiments that have been conducted by the plant breeding community.

2.2 *Ex-Ante* Economic Impact Analysis of Agricultural Technology

The literature analyzing the economic impact of agricultural technology adoption includes two categories: the *ex-ante* analysis and *ex-post* evaluation, which are defined by the analysis as being conducted before and after adoption. As for the evaluation after adoption, the *ex-post* analysis, problems of methodology and data are the main challenges. The key difficulty in the *ex-post* model is simultaneity (Doss, 2016). A study (Zepeda, 1994) specifically addressed this issue by pointing out a single equation approach was subject to simultaneity bias as productivity and technology adoption were jointly decided. Another problem is the difficulty to differentiate adopter and non-adopter. It is hard to compare the productivity gains between these two groups, because of selection bias and large correlation between adoption decision and other factors influencing productivity (Doss, 2016; Bizimana, 2018). Furthermore, many researchers doubt the validity of cross-sectional data used to analyze technology adoption, which leads to ignorance of the inherent dynamic pattern of technology adoption, such as the long-term learning process, sequential technology adoption, and influence on wealth accumulation.

Due to the fact that farmers may focus more on the future return of a new technology instead of extra-rational factors cared typically more important to sociologists (Rosenberg, 1976), and this thesis examines the early stages of technology adoption, the *ex-ante* economic analysis is the focal point. Measuring economic impact of applying a new technology is complicated especially in the perennial fruit industry, because adoption results reply on multiple factors, like location, weather and plant varieties as

Lordan stated (2018). In his research, farm-level data was analyzed, and net present value model was applied in a spreadsheet framework to generate the economic results in applying technology packages. The net present value model is ideal to integrate all possible sources of incomes and costs (Peabody, 2007), and simplify a sensitivity analysis that enables research to observe how a small modification of a model parameter influences the overall results (Doerflinger, 2015). Lordan (2018) also conducted a sensitivity analysis to evaluate how changes of fruit price, tree price and yield affect the profitability of orchard. That is necessary for demonstrating the sensitivity of economic consequences to oscillations of yield and price. However, the model utilizing specific farm-level data is unable to encompass risk and uncertainties from real world.

For the purpose of incorporating agricultural risk, the stochastic process that comprises volatility and drift rate of fluctuating variable was introduced to simulate the price and yield movements in a state-level background (Ho, 2017; Price, 1999). This methodology embodies uncertainties in production and market by assuming yield and price follow geometric Brownian motions (GBM). In GBM, temporal variations are independent of each other, in virtue of adequate market efficiency that all arbitrage opportunities are instantaneously exploited, so that nothing from the past can be used in predictions (Turvey, 2014). Although, this model seems like a plausible technique to simulate price, it is not applicable for farm-level yield data. The reason is that strong biennial tendency of perennial fruit yield violates the geometric Brownian motion assumption, which means another model is needed to simulate the distribution of yield.

The method comprising yield and price variabilities and encompassing intra-and intertemporal correlation is farm-level simulation model applied by Richardson (2000). As it considers intertemporal correlation, the biennial tendency of perennial fruit is included. Moreover, this model controls the heteroscedasticity of stochastic variables over time by utilizing Monte Carlo simulation to simultaneously generate different yield and income distributions in an orchard over the long run. The key output of this method was distribution of the net present value, which exhibits the future economic impacts of applying technology of the farm-level.

2.3 Expected Utility Function

The expected utility function which incorporates risk preferences, can be utilized to represent the technology adoption decision over a choice set based on economic. A basic assumption is that an individual has a preference ordering over a choice set. An individual prefers choice A to choice B if and only if choice A is assigned a larger number than choice B by the utility function. This concept is then extended in choice analysis under uncertainty. Individuals make choices to maximize their utility function, or, equivalently, minimize risk measures. The idea of creating risk measures, and combining with utility function was originated by Daniel Bernoulli (Eeckhoudt, 2005). He proposed that people made decisions to obtain maximum utility instead of generating the largest linear expected monetary result. Therefore, the concave shape of utility function could more precisely describe a risk-averse individuals' decision-making behaviors, as intuitively, an individual who would value the increase of wealth higher when he/she is poor comparing with the situation when he/she is rich, as shown in the figure 2-1.

The idea in figure 2-1 can be explained with a gambling example. Suppose a gamble is designed to flip a coin, an individual can obtain \$400 on one side (point A in figure 4), \$1200 in other side (point B in figure 4). The expected value of the gamble is: $\frac{1}{2} \times 400 + \frac{1}{2} \times 1200 = 800$. For most people who dislike risk, they usually prefer obtain a certain result that is more than a minimal result (\$400 in this example) but less than an expected value (\$800) instead of taking the gamble that having a half opportunity to only obtain the minimal result (\$400). So, a risk-averse individual's utility is described as a concave function where the expected utility value (point C: E(U)) is obtained before the utility of expected value (point D: U(E)), as the tendency of concave curve increases faster in the beginning. We can solve the formula: E(U) = U(CE) to generate the certainty equivalent (point E) to represent the result that a risk-averse individual can accept with certainty instead of taking the gamble. The distance between the certainty equivalent and the expected value of the gamble (\$800) is the risk premium (RP), which is calculated by RP = E(w)-CE, where w denotes the wealth. Risk premium represents the amount the individual can accept in order to obtain an assured result instead of taking a gamble. Additionally, for other two situations, the utility function is convex if an individual is risk-loving ($U''(W) > 0$); and the utility function is linear if an individual is risk-neutral ($U''(W) = 0$).

Furthermore, Bernoulli's theory provided a foundation for establishment of risk measures that reflect the curvature of a utility function. Arrow (1963) and Pratt (1964) introduced two standard risk measures: the absolute risk aversion and relative risk aversion, which both reflect individual's dislike of risk. The absolute risk aversion can be represented by:

(2.1) $$A(W) = -U''(W)/U'(W)$$

Where W denotes wealth, $U''(W)$ denotes the second derivative of utility function, also reflects the curvature, and $U'(W)$ is the first derivative of utility function. The $U'(W)$ helps to standardize the absolute risk aversion as a denominator (Moschini, 2001). The absolute risk aversion demonstrates conditions in which total wealth has a varied non-random component (initial wealth), and a fixed random part incorporating risk (income). Arrow indicated the underlying intuition was that the wealthier the individual is, the probability he/she undertakes a risky project is higher. Therefore, the absolute risk aversion is decreasing as the wealth increases. In conditions where the income and initial wealth simultaneously change proportionally, relative risk aversion is suitable to use, denoted by:

(2.2) $$R(W) = -(U''(W)/U'(W)) \times W$$

Arrow proposed the less likely the individual is willing to undertake the risky project as the proportion of initial wealth and risky project increase by the same amount. That is to say the richer the individual is, the smaller proportion of risky project he/she will hold in assets portfolio. Therefore, the relative risk aversion is increasing as the wealth increases (Bar-Shira, 1997).

In the applied economics field, as researchers are interested in measuring risk aversions, there are two classical utility functions that are convenient to input constant risk aversions obtained by studies to acquire certainty equivalent to reflect a value of a project incorporating risk. They are the constant absolute risk aversion (CARA) utility function:

(2.3) $U(w) = -e^{-wr_a}$, where w denotes wealth, r_a denotes the coefficient of absolute risk aversion.

The constant relative risk aversion (CRRA) function is:

(2.4) $\mathrm{U(w)} = \begin{cases} \frac{w^{1-r_r}}{1-r_r} & if\ r_r > 0 \quad \neq 1 \\ ln(w) & if\ r_r = 1 \end{cases}$, where w denotes wealth, r_r denotes the coefficient of relative risk aversion (Moschini, 2001).

2.4 Risk Aversions for Farmers

Much research has estimated coefficients of risk aversions and related utility function forms for farmers. Lins (1981) introduced three common approaches to measuring risk aversions: directly elicit it from utility functions, conduct experiments, and through the use of econometrics. He also pointed out underlying problems for each of these methods. The direct elicitation from utility functions limits performances of risk aversions. For example, the negative exponential utility function (CARA utility function) already assumes constant absolute risk aversion and increasing relative risk aversion, and the CRRA utility function assumes constant relative risk aversion and decreasing absolute risk aversion. However, famers' risk attitudes are observed to be equivocal, can be constant, decreasing and increasing (Pope, 1982). Another problem is due to the complexity that occurs in reality, the biggest challenge of doing experiments is to design questionnaires without interviewer bias. In addition, econometrics techniques often suffer influences of unrelated factors.

After recognizing various problems, different kinds of results generated by these three methods are summarized in table 2-1. Binici (2003) and Gomez-Limon (2002) estimate risk aversions by applying direct elicitation. Binici (2003) utilized four kinds of utility function in measuring risk attitudes of 200 Turkish farmers. The results from the negative exponential utility function are all farmers that are risk averse with mean of absolute risk aversion 0.1090 under 50 billion (Turkish lira)$^{-1}$. For expo-power utility function and power utility function, one or two farmers are identified as risk-loving with mean absolute risk aversion 0.0588. For cubic utility function, 15 farmers are classified as risk-preferring, also with mean absolute risk aversion 0.0588. Gomez-Limon (2002) relied on multi-attributes utility theory concluded Northern Spain farmers' weighted importance of production objectives, the maximization of gross margin is the most important goal with 56.4% weighted importance and minimizing risk is of 31.8% importance. The average values of absolute risk aversion and relative risk aversion are 0.00010 (per 1 €) and 4.5, respectively. Lin (2015) estimated Korea apple farmers' relative risk aversion by utilizing two stage questionnaires and assuming that relative risk aversion follows a log-normal distribution. The resulted mean is 10.915 with standard deviation of 7.516 and these were suggested to be used as parameters in impact analysis of risk management tools. Furthermore, Bar-Shira (1997), and Kumbhakar

(2002) estimated risk aversions applying econometrics methods. Bar-Shira utilized an instrumental logit model to generate the mean value of absolute risk aversion 4.5e-6 with standard deviation 3.2e-8, and relative risk aversion with mean 0.611 and 0.0086 standard deviation for Israeli farmers. Kumbhakar (2002) regressed on Cobb-Douglas production function and used flexible utility function to obtain ranges of absolute risk aversion from 0.3 to 8.47, and relative risk aversion from 1.44 to 8.60 for Norway salmon farmers.

In all, based on the study from Raskin and Cochran (1986), the range of absolute risk aversion is inconsistent, varies from -0.00001 to infinity. Therefore, on the basis of the initial wealth data in this thesis, we set the range of absolute risk aversion between 0.0001 to 0.001. In the research from Röhrig (2018), 1 to 3 relative risk aversion is used to calculate German apple farmers' certainty equivalents, and based on the literature we summarized, we set the range of relative risk aversion between 1 to 6.

2.5 The Economic Consequence of Adopting Geneva Apple Rootstocks

Due to limited amount of research that has conducted economic impact analysis of technology adoption in the apple industry, this thesis aimed to fill that gap. Two closely related papers are from Busdieker-Jesse (2016) and Nogueira (2016), who applied temporal and spatial partial equilibrium model to analyze the welfare impact of technology on controlling fire blight. In addition, there are farm-level impact analysis studies (Lordan, 2018; Lordan, 2019), but they used deterministic data from field trials without incorporating risk. A similar study only applying constant relative risk aversion function to analyze apple farming technology options was conducted by Röhrig (2018) for German apple farmers. The goal of this thesis is to utilize farm-level data to evaluate technology adoption possibilities for New York State apple farmers considering new rootstocks by incorporating risk.

FIGURE

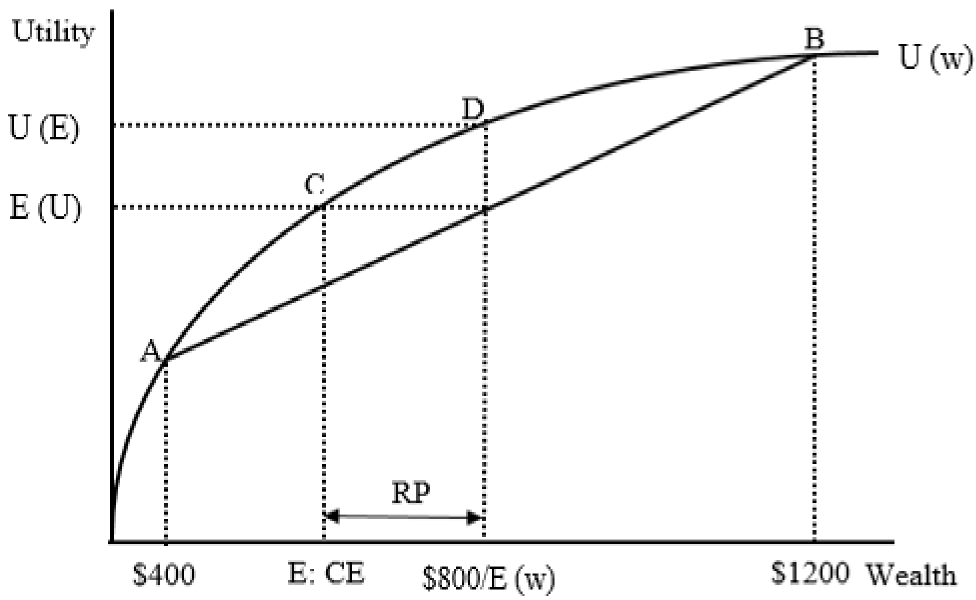

Figure 2-1 Utility Function Graph of a Gamble Example

TABLE

Author	Research	Absolute Risk Aversion	Relative Risk Aversion
Binici, T., Koc, A. A., Zulauf, C. R., & Bayaner, A.	Risk attitudes f farmers in terms of risk aversion: A case study of lower Seyhan plain farmers in Adana province, Turkey.	Negative exponential utility function: 0.1090 Expo-power utility function/Power utility function: 0.0588 Cubic utility function: 0.0588 (Per 50 billion Turkish lira)	
Gomez-Limon, J. A. & Arriaza Balmón, M.	Agricultural risk aversion revisited: A multicriteria decision-making approach	0.00010 (Per 1 Euro)	4.5
Lin, Q. L., Yeo, J. H., & Kim, T. K.	Measuring the Relative Risk Aversion Coefficients of Apple Farmers		log-normal distribution with mean 10.915 and standard deviation 7.516
Bar-Shira, Z., Just, R. E., & Zilberman, D.	Estimation of farmers' risk attitude: an econometric approach	mean value of absolute risk aversion 4.5e-6 with standard deviation 3.2e-8 (Per 1 dollar)	mean 0.611 and 0.0086 standard deviation
Kumbhakar, S. C.	Risk preferences and technology: A joint analysis. Marine Resource Economics	0.3 to 8.47 (Per 3,340 Norwegian Krone)	1.44 to 8.60

Table 2-1 An overview of selected studies measuring risk aversion among agricultural producers

Chapter 3 Data Description

3.1 Study Area

The two locations where primary data were collected included orchards on the Dressel farm and the VandeWalle farm. The Dressel farm is located in Southeast New York State in the Hudson Valley, Ulster County (Reig, 2019), on the average, harvest 150,000 bushels from 20 different varieties of apples on more than 350 acres. It is a family owned farm with Cornell Alumni farmers working with scientists from the rootstock breeding program. The VandeWalle farm is located in Western New York State, in the Town of Sodus, in Wayne County. It has approximately 470 acres dedicated to growing apple trees. Two farms are representative in terms of location, weather and business operations for New York State apple farms, and therefore, we decide to use the field trial data from Dressel farm and VandeWalle farm to simulate our model, and to identify the economic impact of Geneva rootstocks.

In 2006, two 2.47 acre orchard trials were established at both farms to test Cornell-Geneva rootstocks (G11, G41, G6210) and to compare them to current rootstocks (B9, M9, M26) by applying four planting systems: Slender Pyramid (SP) (trees spaced at 2.44m×4.88m, 340 trees per acre); Vertical Axis (VA) (trees spaced at 1.83m×4.27m, 519 trees per acre); Slender Axis (SA) (trees spaced at 1.22m×3.66m, 908 trees per acre); and Tall Spindle (TS) (trees spaced at 0.91m×3.35m, 1320 trees per acre). Both sites had previously been planted apples and were not fumigated before planting the plots with Geneva rootstocks; this was done to test for replant disease pressure. Trees were irrigated each year through drip lines. Average annual precipitation for the Dressel farm was 1000m and was 990m for the VandeWalle farm.

3.2 Experimental Data

Our analysis utilized data from three sources: 1) the Geneva apple rootstocks breeding program, 2) Cornell University Department of Applied Economics and Management, and 3) Washington State Tree Fruit Association. The main agronomic data are from the Geneva apple rootstocks breeding program, and include 10-year (2007-2016) yield data (kilogram per tree) plus the color and size data for fruit from 157 trees across the two locations (Dressel farm, VandeWalle farm), three varieties (Fuji, Gala, Honeycrisp), four systems (Slender Pyramid, Vertical Axis, Slender Axis, Tall Spindle), and six rootstocks (B9, M9, M26, G11, G41, G6210). The assignments of varieties to locations are unbalanced, and the distributions of rootstocks to different planting systems are unbalanced. At the Dressel farm, the varieties Fuji and Gala are grown on Slender Pyramid (SP) for M26, G6210; on Vertical Axis (VA) for G41, M9; on Slender Axis (SA) for G41, G11, B9, M9; and on Tall Spindle (TS) for G41, G11, B9, M9. As for VandeWalle farm, Honeycrisp and Gala, are grown on the different rootstocks and different planting systems. Specific details for the locations, varieties, planting systems, densities of planting systems, rootstocks and number of trees are shown in table 3-1 and table 3-2.

Economic data is drawn from the Fruit Farm Business Summary (2008) collected by Cornell University Department of Applied Economics and Management from 25 fruit farm businesses located in New York State. It includes establishment costs, variable costs (including pesticide costs, herbicide costs, fungicide costs, thinning costs and fertilizer costs), fixed costs, pruning costs and harvest costs. The details are shown in tables 3-3, table 3-4, and table 3-5.

Price data are from the Washington State Tree Fruit Association for different colors and different sizes, and were converted to New York State apple prices using the New York State and Washington State apple price ratio from USDA (ERS, 2010). We then linked the price data with color and size information that was generated from the rootstock for fruit harvested overtime from 157 trees. The experimental 8-year apple price data for New York State for different colors and sizes are shown in table 3-6, table 3-7, and table 3-8.

TABLE

Table 3-1 Dressel Farm: A Description of the Variety, System, Rootstock in the Experiment

Location	Variety	System (Density: Trees/Acre)	Rootstock	# of Tree
Dressels Farm	Fuji	SA (908)	G41	3
			G11	3
			B9	3
			M9	3
		TS (1320)	G41	3
			G11	3
			B9	3
			M9	3
		SP (340)	G6210	3
			M26	3
		VA (519)	G41	3
			M9	3
	Gala	SA (908)	G41	3
			G11	3
			B9	3
			M9	3
		TS (1320)	G41	3
			G11	3
			B9	3
			M9	4
		SP (340)	G6210	3
			M26	3
		VA (519)	G41	3
			M9	3

Table 3-2 VandeWalle Farm: A Description of the Variety, System, Rootstock in the Experiment

Location	Variety	System (Density: Trees/Acre)	Rootstock	# of Tree
VandeWalle Farm	HC	SA (908)	G41	3
			G11	3
			B9	3
			M9	3
		TS (1320)	G41	3
			G11	3
			B9	3
			M9	3
		SP (340)	G6210	3
			M26	3
		VA (519)	G41	3
			M9	3
	Gala	SA (908)	G41	3
			G11	3
			B9	3
			M9	3
		TS (1320)	G41	3
			G11	3
			B9	3
			M9	3
		SP (340)	G6210	3
			M26	3
		VA (519)	G41	3
			M9	3

Table 3-3 Establishment Costs for starting an orchard in the New York State

Establishment costs	
Land value	$2428.17/acre
Land preparation	$728.45/acre
Labor: planting and training	$364.23/acre
Tree price	$9.50/tree
Trellising	
Post cost	$10/post
Conduit/stake cost	$1.55/stake
Wire cost	$0.03/m
Post pounding	$80.94/acre
Labor: trellis install	$210.44/acre
Miscellaneous	
Irrigation material	$1011.74/acre
Labor: install irrigation	$404.68/acre

Table 3-4 Variable Costs for Operating an Orchard in the New York State

Year	IPM ($/acre) Fungicide	Herbicide	Pesticide	Fertilizer ($/acre)	Thinning ($/acre) Honeycrisp	Fuji	Gala	**Total variable cost ($/acre)** **Honeycrisp**	**Fuji**	**Gala**
0	0	19	0	226	0	0	0	**282**	**282**	**282**
1	102	32	43	344	0	0	0	**599**	**599**	**599**
2	140	34	43	83	0	0	0	**344**	**344**	**344**
3	239	10	140	175	16	59	16	**666**	**716**	**666**
4	258	35	226	143	42	64	86	**810**	**835**	**860**
5	290	51	268	247	64	128	137	**1057**	**1131**	**1141**
6	243	17	327	167	64	128	137	**940**	**1014**	**1024**
7	235	35	253	199	64	128	137	**904**	**977**	**988**
8	295	50	188	215	64	128	137	**933**	**1007**	**1017**
9	295	50	256	199	64	128	137	**993**	**1067**	**1077**
10	295	50	256	167	64	128	137	**956**	**1030**	**1040**
11	295	50	256	198	64	128	137	**992**	**1066**	**1076**
12	295	50	256	198	64	128	137	**992**	**1066**	**1076**
13	295	50	256	198	64	128	137	**992**	**1066**	**1076**
14	295	50	256	198	64	128	137	**992**	**1066**	**1076**
15	295	50	256	198	64	128	137	**992**	**1066**	**1076**
16	295	50	256	198	64	128	137	**992**	**1066**	**1076**
17	295	50	256	198	64	128	137	**992**	**1066**	**1076**
18	295	50	256	198	64	128	137	**992**	**1066**	**1076**
19	295	50	256	198	64	128	137	**992**	**1066**	**1076**
20	295	50	256	198	64	128	137	**992**	**1066**	**1076**

Table 3-5 Harvest Costs, Fixed Costs, Pruning Costs of Operating an Orchard in the New York State

Harvest costs	Honeycirsp	Gala	Fuji
Base Picking Cost ($/Bin)	35.00	24.00	24.00
Picking Employer Taxes (%)	0.15	0.15	0.15
Total Picking Cost ($/Bin)	40.25	27.60	27.60
Total Picking Cost ($/kg)	0.11	0.08	0.08
Fixed costs ($/acre)	607.04	607.04	607.04
Pruning costs			
Skilled labor ($/hour)	13.06	13.06	13.06
Unskilled labor ($/hour)	18.09	18.09	18.09

Table 3-6 Fuji Apple Price for 5 grades, 8 years (2009-2016)

Grower returns ($/kg)		Year	Size Category								
Color Category	Variety		<115 g	115<133 g	133<153g	153<175g	175<199g	199<225g	225<253g	253<283g	>283g
XX Fancy	Fuji	2009	0.88	0.32	0.33	0.40	0.44	0.57	0.82	0.66	0.81
		2010	0.99	0.40	0.76	0.57	0.63	0.82	1.04	0.78	0.97
		2011	0.91	0.69	0.93	0.97	0.66	0.92	1.15	0.93	1.14
		2012	0.98	0.51	1.01	1.38	0.83	1.18	1.04	1.22	1.38
		2013	1.10	0.76	0.89	1.20	0.95	1.20	1.22	1.19	1.16
		2014	1.10	0.66	0.78	1.26	0.88	1.07	0.96	1.15	0.95
		2015	1.16	0.74	1.16	1.53	0.92	1.35	1.14	1.36	1.15
		2016	1.13	0.70	0.73	1.31	0.86	1.14	1.22	1.25	1.14
X Fancy	Fuji	2009	0.50	0.24	0.29	0.31	0.38	0.54	0.67	0.62	0.62
		2010	0.68	0.47	0.76	0.54	0.59	0.74	0.87	0.73	0.78
		2011	0.73	0.41	0.91	0.95	0.61	0.82	0.99	0.76	0.87
		2012	0.95	0.48	1.20	1.15	0.79	1.09	0.94	0.99	1.12
		2013	0.95	0.68	0.84	1.22	0.84	0.92	1.01	1.02	0.98
		2014	0.99	0.51	0.74	1.11	0.76	0.83	0.83	0.95	0.83
		2015	1.10	0.86	1.12	1.44	0.86	1.13	1.05	1.12	0.98
		2016	1.12	0.58	0.93	1.18	0.82	0.89	0.96	1.07	0.95
Fancy	Fuji	2009	0.18	0.26	0.26	0.25	0.22	0.36	0.44	0.43	0.37
		2010	0.48	0.27	0.35	0.36	0.40	0.49	0.58	0.52	0.52
		2011	0.62	0.24	0.30	0.37	0.34	0.62	0.66	0.65	0.75
		2012	0.52	0.49	1.11	1.00	0.57	0.79	0.86	0.85	0.92
		2013	0.78	0.46	0.69	0.77	0.66	0.70	0.67	0.71	0.87
		2014	0.58	0.93	0.47	0.62	0.61	0.57	0.60	0.62	0.75
		2015	0.79	0.74	0.37	1.04	0.52	0.67	0.70	0.72	0.87
		2016	0.77	0.27	0.61	1.04	0.44	0.62	0.64	0.62	0.70
No.1	Fuji	2009	0.43	0.30	0.26	0.30	0.26	0.59	0.55	0.57	0.74
		2010	0.55	0.73	0.34	0.40	0.31	0.51	0.76	0.60	0.75
		2011	0.59	0.26	0.38	0.40	0.34	0.59	0.79	0.69	0.94
		2012	0.90	0.39	0.49	0.54	0.44	0.69	0.71	0.76	0.95
		2013	0.94	0.48	0.53	0.60	0.45	0.70	0.70	0.73	0.81
		2014	0.73	0.31	0.42	0.44	0.37	0.63	0.74	0.67	0.70
		2015	1.13	0.71	0.86	0.53	0.43	0.83	0.82	0.84	0.99
		2016	0.97	0.49	0.41	0.45	0.36	0.51	0.63	0.65	0.67
Utility	Fuji	2009	0.13	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
		2010	0.19	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2011	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2012	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2013	0.17	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
		2014	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2015	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2016	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23

Table 3-7 Gala Apple Price for 5 grades, 8 years (2009-2016)

Grower returns ($/kg)		Year	Size Category								
Color Category	Variety		<115 g	115<133 g	133<153g	153<175g	175<199g	199<225g	225<253g	253<283g	>283g
XX Fancy	Gala	2009	0.82	0.30	0.31	0.37	0.41	0.46	0.78	0.66	0.81
		2010	0.93	0.38	0.71	0.53	0.59	0.67	0.99	0.78	0.97
		2011	0.86	0.65	0.87	0.91	0.62	0.75	1.10	0.93	1.14
		2012	0.92	0.48	0.94	1.30	0.78	0.96	0.99	1.22	1.38
		2013	1.03	0.72	0.83	1.13	0.90	0.98	1.17	1.19	1.16
		2014	1.03	0.62	0.74	1.18	0.83	0.87	0.91	1.15	0.95
		2015	1.09	0.70	1.09	1.44	0.86	1.10	1.09	1.36	1.15
		2016	1.06	0.65	0.69	1.23	0.81	0.92	1.16	1.25	1.14
X Fancy	Gala	2009	0.46	0.23	0.27	0.29	0.35	0.43	0.63	0.62	0.62
		2010	0.63	0.44	0.71	0.50	0.55	0.58	0.82	0.73	0.78
		2011	0.68	0.38	0.85	0.88	0.57	0.65	0.94	0.76	0.87
		2012	0.88	0.45	1.12	1.07	0.74	0.86	0.89	0.99	1.12
		2013	0.88	0.63	0.78	1.13	0.78	0.73	0.96	1.02	0.98
		2014	0.92	0.48	0.68	1.03	0.71	0.65	0.79	0.95	0.83
		2015	1.02	0.80	1.04	1.34	0.80	0.90	0.99	1.12	0.98
		2016	1.04	0.54	0.86	1.10	0.76	0.71	0.91	1.07	0.95
Fancy	Gala	2009	0.17	0.24	0.24	0.23	0.20	0.27	0.42	0.43	0.37
		2010	0.44	0.25	0.32	0.33	0.36	0.37	0.54	0.52	0.52
		2011	0.57	0.21	0.27	0.33	0.31	0.47	0.62	0.65	0.75
		2012	0.47	0.45	1.01	0.91	0.52	0.59	0.81	0.85	0.92
		2013	0.71	0.42	0.62	0.70	0.60	0.53	0.63	0.71	0.87
		2014	0.53	0.85	0.42	0.57	0.55	0.43	0.56	0.62	0.75
		2015	0.72	0.67	0.34	0.95	0.47	0.50	0.65	0.72	0.87
		2016	0.70	0.25	0.55	0.95	0.40	0.47	0.60	0.62	0.70
No.1	Gala	2009	0.38	0.26	0.23	0.27	0.23	0.41	0.51	0.57	0.74
		2010	0.49	0.64	0.30	0.35	0.27	0.35	0.71	0.60	0.75
		2011	0.52	0.23	0.34	0.36	0.29	0.41	0.73	0.69	0.94
		2012	0.79	0.34	0.43	0.48	0.38	0.48	0.66	0.76	0.95
		2013	0.83	0.42	0.46	0.53	0.40	0.49	0.65	0.73	0.81
		2014	0.64	0.28	0.37	0.39	0.33	0.44	0.69	0.67	0.70
		2015	1.00	0.63	0.75	0.47	0.37	0.58	0.76	0.84	0.99
		2016	0.85	0.43	0.36	0.40	0.32	0.35	0.58	0.65	0.67
Utility	Gala	2009	0.13	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
		2010	0.19	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2011	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2012	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2013	0.17	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
		2014	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2015	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2016	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23

Table 3-8 Honeycrisp Apple Price for 5 grades, 8 years (2009-2016)

Grower returns ($/kg)		Year	Size Category								
Color Category	Variety		<115 g	115<133 g	133<153g	153<175g	175<199g	199<225g	225<253g	253<283g	>283g
XX Fancy	Honeycrisp	2009	1.79	0.66	0.68	0.81	1.20	1.21	1.89	1.59	1.94
		2010	2.03	0.82	1.55	1.16	1.71	1.75	2.41	1.88	2.34
		2011	1.87	1.41	1.90	1.99	1.79	1.96	2.67	2.25	2.74
		2012	2.00	1.05	2.06	2.82	2.27	2.51	2.40	2.93	3.33
		2013	2.25	1.56	1.82	2.46	2.60	2.56	2.83	2.86	2.79
		2014	2.25	1.35	1.60	2.57	2.40	2.28	2.22	2.76	2.29
		2015	2.37	1.51	2.38	3.13	2.51	2.88	2.65	3.29	2.76
		2016	2.30	1.42	1.50	2.67	2.35	2.42	2.82	3.02	2.76
X Fancy	Honeycrisp	2009	1.09	0.54	0.63	0.67	1.11	1.21	1.63	1.59	1.59
		2010	1.50	1.03	1.67	1.19	1.75	1.65	2.13	1.86	1.99
		2011	1.59	0.90	2.00	2.07	1.80	1.85	2.42	1.94	2.23
		2012	2.08	1.06	2.63	2.53	2.35	2.45	2.31	2.52	2.86
		2013	2.08	1.48	1.85	2.67	2.50	2.06	2.48	2.61	2.49
		2014	2.16	1.12	1.61	2.43	2.25	1.85	2.04	2.42	2.12
		2015	2.41	1.89	2.45	3.15	2.54	2.54	2.57	2.86	2.50
		2016	2.46	1.28	2.03	2.59	2.43	2.00	2.35	2.72	2.42
Fancy	Honeycrisp	2009	0.46	0.65	0.66	0.64	0.78	0.90	1.21	1.22	1.06
		2010	1.21	0.69	0.88	0.91	1.39	1.22	1.57	1.49	1.49
		2011	1.56	0.59	0.75	0.92	1.19	1.53	1.81	1.83	2.13
		2012	1.29	1.24	2.79	2.51	1.99	1.95	2.34	2.42	2.63
		2013	1.94	1.15	1.72	1.94	2.30	1.74	1.83	2.03	2.47
		2014	1.45	2.33	1.17	1.56	2.12	1.41	1.64	1.76	2.12
		2015	1.98	1.85	0.93	2.60	1.80	1.65	1.89	2.05	2.47
		2016	1.92	0.69	1.52	2.61	1.55	1.55	1.73	1.77	1.99
No.1	Honeycrisp	2009	0.76	0.52	0.45	0.53	0.65	0.95	0.97	1.06	1.38
		2010	1.17	1.53	0.72	0.85	0.93	0.98	1.64	1.35	1.69
		2011	1.31	0.58	0.86	0.90	1.07	1.20	1.79	1.65	2.23
		2012	2.01	0.86	1.09	1.20	1.40	1.42	1.62	1.80	2.26
		2013	2.11	1.06	1.17	1.34	1.44	1.43	1.59	1.73	1.93
		2014	1.62	0.70	0.93	0.98	1.19	1.29	1.69	1.59	1.66
		2015	2.53	1.59	1.91	1.18	1.36	1.70	1.87	2.01	2.36
		2016	2.16	1.09	0.92	1.01	1.17	1.04	1.43	1.54	1.59
Utility	Honeycrisp	2009	0.13	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
		2010	0.19	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2011	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2012	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2013	0.17	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
		2014	0.16	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2015	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		2016	0.17	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23

Chapter 4 Method and Quantitative Framework

4.1 Overview

This Chapter introduces a conceptual framework for the economic impact analysis of the potential adoption of Geneva rootstocks, using three models to quantify the net returns of technology investments for apple farmers and for society. The farm-level simulation model forecasts price and yield distributions based on historical data. The financial model calculates revenue flows through multiplying price with yield, deducts costs, discounts annual flows and evaluates the accumulated net present values. The expect utility function assumes an accumulated net present value distribution as a net return of adopting a technology to demonstrate the farmer's adoption decision based on calculated certainty equivalents.

4.2 Farm-level Simulation Model

Simulation has played an important role in aiding decision making and as a tool for condition risk analysis. The simulation in this thesis is to determine how risk influences the decision to adopt a new technology across different distributions of key variables. These distributions are established based on historical data, simulated by applying Monte Carlo procedures to select values for designed distributions in 500 iterations. This Monte Carlo process is utilized in the Farm-level Simulation Model (Bizimana, 2018) and is especially useful to generate empirical distributions of key output variables under limited sample size, as data collection of this new technology in the perennial fruit industry is usually slow. Another advantage of this model is it incorporates intracorrelation (within time) and inter-correlation (between time) effects, and thus captures the heteroscedasticity between random variables over time.

The process of applying the Farm-level Simulation Model is presented by Richardson (2000) by utilizing *Simetar* which is an Excel add-in tool used for matrix calculation and Monte Carlo simulation. The first step is to separate the random and deterministic components for each of the stochastic variables. For a limited sample size, the trend of each variable is usually difficult to identify, so the sample mean of the data is used as the deterministic component.

(4.1) $$X_{it} = \hat{X}_{it} + \hat{e}_{it}$$

(4.2) $$\hat{X}_{it} = \bar{X}_i$$

And for the second step, the relative variability of each observation, denoted by D_{it}, is calculated by dividing the random part into the deterministic part:

(4.3) $$D_{it} = \hat{e}_{it}/\hat{X}_{it}$$

The third step is to sort D_{it} from minimum to maximum into S_{it} which denotes the sorted relative variability. Creating pseudo-minimums, denoted by $Smin_i$, and pseudo-maximum, denoted by $Smax_i$, are used to establish an empirical range of the relative variability. Assuming D_{it} is uniformly distributed, we assign equal probability of each year to each variable, and calculate cumulative probabilities denoted as $P(S_{it})$ by for each S_{it}:

(4.4)
$$\begin{gathered} S_{it} = \text{Sorted } (D_{it} \text{ from min to max}) \\ Smin_i = \text{Minimum } (S_{it}) \\ Smax_i = \text{Maximum } (S_{it}) \\ P(Smin_i) = 0.0 \\ P(S_{i1}) = (1/T) \times 0.5 \end{gathered}$$

$$P(S_{i2}) = (1/T)+P(S_{i1})$$
$$P(S_{i3}) = (1/T)+P(S_{i2})$$
$$\ldots\ldots$$
$$P(S_{in}) = (1/T)+P(S_{i(n-1)})$$
$$P(Smax_i) = 1.0$$

The fourth step is to generate an intra-temporal correlation matrix by calculating correlations between unsorted random component ($\hat{e}_{it}$) within time, and generate inter-temporal correlation matrix by calculating correlations of each unsorted random variable ($\hat{e}_{it}$) over time. For example, in a situation that simulates eight variables and forecasts each variable for 10 years, the intra-temporal correlation matrix is 8×8 for X_i and X_j, and inter-temporal correlation matrix is 10×10 for each variable X_{it} with X_{it-1}.

(4.5) Intra-Temporal Correlation Matrix for X_i and X_j:

$$\boldsymbol{\rho_{ij}} = \begin{vmatrix} \rho_{\hat{e}_{1t}\hat{e}_{1t}} & \rho_{\hat{e}_{1t}\hat{e}_{2t}} & \rho_{\hat{e}_{1t}\hat{e}_{3t}} & \rho_{\hat{e}_{1t}\hat{e}_{4t}} & \rho_{\hat{e}_{1t}\hat{e}_{5t}} & \rho_{\hat{e}_{1t}\hat{e}_{6t}} & \rho_{\hat{e}_{1t}\hat{e}_{7t}} & \rho_{\hat{e}_{1t}\hat{e}_{8t}} \\ 0 & \rho_{\hat{e}_{2t}\hat{e}_{2t}} & \rho_{\hat{e}_{2t}\hat{e}_{3t}} & \rho_{\hat{e}_{2t}\hat{e}_{4t}} & \rho_{\hat{e}_{2t}\hat{e}_{5t}} & \rho_{\hat{e}_{2t}\hat{e}_{6t}} & \rho_{\hat{e}_{2t}\hat{e}_{7t}} & \rho_{\hat{e}_{2t}\hat{e}_{8t}} \\ 0 & 0 & \rho_{\hat{e}_{3t}\hat{e}_{3t}} & \rho_{\hat{e}_{3t}\hat{e}_{4t}} & \rho_{\hat{e}_{3t}\hat{e}_{5t}} & \rho_{\hat{e}_{3t}\hat{e}_{6t}} & \rho_{\hat{e}_{3t}\hat{e}_{7t}} & \rho_{\hat{e}_{3t}\hat{e}_{8t}} \\ 0 & 0 & 0 & \rho_{\hat{e}_{4t}\hat{e}_{4t}} & \rho_{\hat{e}_{4t}\hat{e}_{5t}} & \rho_{\hat{e}_{4t}\hat{e}_{6t}} & \rho_{\hat{e}_{4t}\hat{e}_{7t}} & \rho_{\hat{e}_{4t}\hat{e}_{8t}} \\ 0 & 0 & 0 & 0 & \rho_{\hat{e}_{5t}\hat{e}_{5t}} & \rho_{\hat{e}_{5t}\hat{e}_{6t}} & \rho_{\hat{e}_{5t}\hat{e}_{7t}} & \rho_{\hat{e}_{5t}\hat{e}_{8t}} \\ 0 & 0 & 0 & 0 & 0 & \rho_{\hat{e}_{6t}\hat{e}_{6t}} & \rho_{\hat{e}_{6t}\hat{e}_{7t}} & \rho_{\hat{e}_{6t}\hat{e}_{8t}} \\ 0 & 0 & 0 & 0 & 0 & 0 & \rho_{\hat{e}_{7t}\hat{e}_{7t}} & \rho_{\hat{e}_{7t}\hat{e}_{8t}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \rho_{\hat{e}_{8t}\hat{e}_{8t}} \end{vmatrix}$$

(4.6) Inter-Temporal Correlation Matrix for X_{it} and X_{it-1}:

$$\boldsymbol{\rho}_{\mathbf{i(t,t-1)}} = \begin{vmatrix} 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \rho_{\hat{e}_{it}\hat{e}_{it-1}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix}$$

The fifth step is to factor the intra-temporal and inter-temporal matrices by using MSQRT formula from *Simetar*:

(4.7) $$\mathrm{R}_{\mathrm{ij}(8\times8)} = \mathrm{MSQRT}(\rho_{\mathrm{ij}(8\times8)})$$

(4.8) $$\mathrm{R}_{\mathrm{i(t,t-1)}(10\times10)} = \mathrm{MSQRT}(\rho_{\mathrm{i(t,t-1)}(10\times10)})$$

The sixth step is to generate independent standard normal deviates (ISND) with a standard normal distribution and mean 0 and standard deviation 1. The seventh step is to multiply the ISNDs with the factored intra-temporal correlation matrix for every year, and to generate the Intra-Temporal Correlated Standard Normal Deviates for the simulated years:

(4.9) $$\mathrm{ISND}_{\mathrm{it}} = \mathrm{Risknormal}(0,1)$$

(4.10) $$\mathrm{IntraCSND}_{\substack{\mathrm{k}=1-10 \\ \mathrm{i}(8\times1)}} = \mathrm{R}_{\substack{\mathrm{k}=1-10 \\ \mathrm{ij}(8\times8)}} \times \mathrm{ISND}_{\substack{\mathrm{k}=1-10 \\ \mathrm{i}(8\times1)}}$$

The eighth step is to capture inter-temporal correlation by multiplying inter-temporal correlation matrix for each variable with the Intra-CSND to generate adjusted correlated standard normal deviates:

(4.11) $$\mathrm{ACSND}_{\substack{k=1-10\\ i(8\times1)}} = \mathrm{R}_{i(t,t-1)(10\times10)} \times \mathrm{IntraCSND}_{\substack{k=1-10\\ i(8\times1)}}$$

The ninth step is to transform the ACSND to uniform deviates by using the *normdist( )* command in Excel to generate correlated uniform deviates:

(4.12) $$\mathrm{CUD}_{i(80\times1)} = normsdist(\mathrm{ACSND}_{i(80\times1)})$$

And then, we simulate an empirical distribution by applying the *EMP( )* formula from Simetar. This function assumes a continuous distribution based on historical data, so it interpolates between specified historical points on the distribution of deviates using the cumulative distribution probabilities denoting by $P(S_{it})$. The direct form of the function is shown below in equation (4.13):

$$\text{Empirical Distribution} = \mathrm{EMP}(S_{it}, P(S_{it}), \mathrm{CUD})$$

Where S_{it} represents an array of N sorted relative variabilities including min and max from step three; P(sorted deviates) is the cumulative probabilities for sorted relative variabilities, including the end points of zero and one; CUD is the correlated uniform deviates generated by applying uniform distributions, and incorporating correlations between variables over time.

Finally, the simulated random values in year k for variable X_i is:

(4.14) $$\widetilde{\mathrm{X}}_{ik} = \widehat{\mathrm{X}}_{ik} \times (1 + \mathrm{EMP}(\mathrm{S}_{it}, \mathrm{P}(\mathrm{S}_{it}), \mathrm{CUD}_{ik}))$$

Where $\widehat{\mathrm{X}}_{ik}$ denotes the deterministic component, and $\widehat{\mathrm{X}}_{ik} \times \mathrm{EMP}(\mathrm{S}_{it}, \mathrm{P}(\mathrm{S}_{it}), \mathrm{CUD}_{ik})$ denotes the random component.

4.3 The Farm Level Financial Model

After generating the yield and price distributions for both the new technology (Geneva rootstocks) and the current technology (traditional rootstocks), the net return can be calculated by subtracting costs from revenue obtained by multiplying yield and price distributions. The net return (NR_{it}) formula is:

$$\widetilde{NR}_{it} = \tilde{Y}_{it} \times \tilde{P}_{it} - TC_{it} \tag{4.15}$$

$$TC_{it} = VC_{it} + FC_{it} + EC_{it} + PC_{it} + HC_{it} \tag{4.16}$$

Where $\widetilde{NR}_{it}$ represents the simulated net return per acre for each technology combination that includes a planting system, cultivar, and rootstocks in each year, $\tilde{Y}_{it}$ represents the simulated yield distribution for each technology combination in each year, $\tilde{P}_{it}$ denotes simulated price distribution per kilogram for each technology combination in each year, and TC_{it} represents total costs for each technology combination in each year. Total costs include variable costs, fixed costs, establishment costs, pruning costs and harvest costs. The VC_{it} represents variable costs for each combination for each year, and this includes pesticide costs, herbicide costs, fungicide costs, and thinning costs. There are three sets of variable costs for each variety, (Fuji, Gala, and Honeycrisp). The FC_{it} represents fixed costs for each combination for each year, include management costs, real estate repair costs, tax costs, insurance costs, utility costs, and miscellaneous costs. Establishment costs (denoted as EC_{it}) for each combination for first two years, include preplant costs, tree costs, and planting system costs. Pruning costs (denoted as PC_{it}) for each combination for each year, calculates by multiplying pruning time per tree with labor cost. Harvest costs (denoted as HC_{it}) for each combination for each year, are calculated by multiplying picking costs per kilogram with yield.

Once the net return per acre for each technology for each year is obtained, the net present value (NPV_{it}) per acre for each combination for each year can be calculated by applying the discount factor. After obtaining the 20-year net present values, the summation of the 20-year net present values are used to generate the accumulated net present values ($ANPV_{it}$) to evaluate the economic performances of the different technology investments. The formulas for computing NPV_{it} and $ANPV_i$ are:

(4.17) $$\widetilde{\mathrm{NPV}}_{\mathrm{it}} = \widetilde{\mathrm{NR}}_{\mathrm{it}}/(1+\mathrm{r})^{\mathrm{t}}$$

(4.18) $$\widetilde{\mathrm{ANPV}}_{\mathrm{i}} = \sum_{t=0}^{20} \widetilde{\mathrm{NPV}}_{\mathrm{it}}\ ,$$

Where $\widetilde{\mathrm{NR}}_{\mathrm{it}}$ is the simulated net return per each combination for each year calculated from above, r is the discount rate, $1/(1+\mathrm{r})^{\mathrm{t}}$ is the discount factor, and $\widetilde{\mathrm{ANPV}}_{\mathrm{i}}$ is the summation of the 20-year net present values.

4.4 Expected Utility Function

After generating the $\widetilde{\mathrm{ANPV}}_{\mathrm{i}}$ by applying the distribution fitting function of @Risk in Excel, the distributions of the resulting $\widetilde{\mathrm{ANPV}}_{\mathrm{i}}$ closely resemble normal distributions, which provides a theoretical foundation of using the normal distribution moment-generating function in the Expected Utility Function.

Suppose a farmer must make decision on whether to adopt the new technology, T_1, or continue using current technology, T_0. The return generated by the new technology is a key parameter of an expected utility function, denoted by R_1, and the same notation for current technology, R_0 (Yassour, 1980). We assume $R_i = \widetilde{ANPV}_i$, so R_i is normally distributed. Economic theory suggests that the individual will choose the one maximizing their expected utility. We apply two sets of utility functions here: the constant absolute risk aversion utility function and the constant relative risk aversion utility function. The constant absolute risk aversion (CARA) is defined as $A(w) = -U''(w)/U'(w)$, where w typically denotes the wealth of a farmer, and here we use the net return from the technology. CARA measures the normalized curvature of a utility function, and it is a practical tool for comparing the risk attitudes of farmers towards different technologies. The constant relative risk aversion (CRRA) is defined as $R(w) = w \times A(w)$, and again we replace w with the net return. It represents the attitudes of risk-aversion decision makers towards technology as a fraction of their net return, which provides an insight on the willingness of farmer to reinvest this technology under a fixed budget setting. In the analysis of this thesis, the utility functions and derived certainty equivalent functions from these two types of risk aversion are utilized to make the technology adoption decision. So the new technology will be adopted if:

$$E_1U(R_1) > E_0U(R_0) \tag{4.19}$$

Where U is the utility function and E_i is an expectation operator for the return distribution of the ith technology. As for the constant absolute risk aversion function, the formula is:

$$U(R) = -e^{-rR} \tag{4.20}$$

Where *r* is the measure of absolute risk aversion, substitute equation (4.20) into (4.19), we obtain: (4.21) $E_1(e^{-rR_1}) < E_0(e^{-rR_0})$

Which is equivalent to:

(4.22)

$$\mathrm{M}_1(-r) < \mathrm{M}_0(-r)$$

Where $\mathrm{M}(t) = \mathrm{E}(e^{tR})$ is the moment generating function of the return probability distribution, when the return probability distribution is normally distributed, the moment generating function is:

(4.23)

$$\mathrm{M}(t) = e^{(\mu t + \sigma^2 \frac{t^2}{2})}$$

Where μ and σ are the mean and the standard deviation. By substituting (4.23) into (4.22), and taking natural logarithm, we obtain:

(4.24)

$$(\mu_1 - \mu_0) - \frac{r}{2}(\sigma_1^2 - \sigma_0^2) > 0$$

The result suggests that the new technology will be adopted if the increase in the mean return exceeds the increase in variance times half of the risk aversion measure.

Furthermore, as (4.25) $\mathrm{E}[\mathrm{U}(\mathrm{R_i})] = \mathrm{U}(\mathrm{CE_i})$, where $\mathrm{CE_i}$ denotes the certainty equivalent, we substitute (4.25) with (4.20), and (4.22) with (4.23) to obtain the certainty equivalent of profit under the ith technology when return is normally distributed: $\mathrm{CE_i} = \mu_i - \sigma_i^2 \frac{r}{2}$. Here the risk premium is $\sigma_i^2 \frac{r}{2}$, where $\frac{r}{2}$ is the price per dollar of variance.

As for the constant relative risk aversion function, the formula is:

(4.26)

$$\mathrm{U(R)} = \begin{cases} \frac{R^{1-\gamma}}{1-r} & if\ \gamma > 0 \quad \neq 1 \\ ln(R) & if\ \gamma = 1 \end{cases}$$

Where γ is the measure of relative risk aversion, R is a return of a technology. Because $\mathrm{E}[\mathrm{U}(\mathrm{R_i})] = \mathrm{U}(\mathrm{CE_i})$, The CE is the inverse of the utility function (Kidane, 2015), therefore, (4.27) $$\mathrm{CE(R)} = \begin{cases} [E(R^{1-\gamma})]^{\frac{1}{1-\gamma}} & if\ \gamma > 0 \ \ \neq 1 \\ e^{E(\ln(R))} & if\ \gamma = 1 \end{cases}.$$

The adoption decision is made based on whether $\mathrm{CE(R_1)} > \mathrm{CE(R_0)}$, and the risk premium (RP) is the difference between the CE and the expected value of return of technology:

(4.28) $$\mathrm{RP} = \mathrm{E(R)} - \mathrm{CE(R)}$$

After outlining our quantitative framework, we apply these three models by incorporating data we presented in Chapter 3. We exhibit our results in Chapter 5 by stating our assumptions at first.

Chapter 5 Results

5.1 Model Assumptions

5.1.1 Assumptions for the Farm Level Simulation Model

The rootstock breeding program collected 10-year yield data for each technology combination (a package of cultivar, system and rootstock). The first assumption is that all trees attain mature stage after the second year, and therefore we use data from years 3-10 to forecast future yields. The final simulation for yields over 20 years include the actual data from the field trials plus simulated data forecasted using the historical data.

Price data across different grades and fruit sizes are collected from trees in the experiment. Because fruit grade data are only from 7 years, we assume the fruit grades in the first three years are the same as the grade in the fourth year. By multiplying prices for different grades with corresponding fruit grade proportion produced by each tree for each year, we generate apple prices over the life span of the overhead.

The total revenue per acre is the product of yield and the corresponding prices for each planting system over 20 years. As for costs, data provided by Fruit Farm Business Summary (White, 2008) is utilized where we adjust the data for inflation. Also, an extra rootstock royalty fee is added for the Geneva apple rootstock program based on a representative nursery price list (Rootstock Price List, 2017). To obtain the net present value per acre, a discounted rate of 6% is calculated by using a weighted average cost of capital (WACC) formula: $r_{wacc}=r_{debt}\times(1-r_{tax})\times D/(E+D)+r_{equity}\times E/(E+D)$, where r_{wacc} is the rate of weighted average cost of capital, r_{debt} is the cost of debt, r_{tax} is the tax rate, r_{equity} is the desired rate of equity, E denotes equity, and D denotes debit (De Vries, 2012; White, 2008). We report the accumulated net present value distribution per acre for each technology package in baseline results that assume no fire blight.

5.1.2 Assumption for Sensitivity Analysis of Fire Blight

The next step is conducting the sensitivity analysis of the net returns from technology adoption assuming different probabilities of fire blight. To simulate the occurrence of fire blight, the timing and infected proportion for the various rootstocks need to be clarified. Based on the previous research (Russo, 2007; Norelli, 2000), fire blight is more likely to occur in a high-density orchard (more than 300 trees per acre) with susceptible but commercially successful apple varieties, like Fuji, Gala, and Honeycrisp. The timing of fire blight is prevalent in a young dwarf orchard. Most fire blight tests for rootstock studies are conducted on 3-year-old trees.

This simulation assumes that varieties Fuji, Gala, Honeycrisp grow on the current rootstocks (M9, M26, B9) and the Geneva rootstocks (G11, G41, G6210) in four high-density systems (SA, TS, SP, VA), and fire blight would happen in the third year. The current solution for fire blight is to replace infected trees, based on proportions of fire blight infected for different rootstocks. The infected proportion represent the severity of fire blight, which means the percentage of infected trees per acre. The research from Russo (2007) showed that for M26, the proportion of fire blight infected ranges from 67% to 93%, which means as for M26, there is 67% to 93% trees per acre that will be infected once the fire blight happens; for M9, the proportion ranges from 56% to 86%;

for B9, the proportion ranges from 3% to 5%; G11 is around 12%; G41 is around 4%. We assume G6210 ranges from 4% to 12%, and the proportion of fire blight infected are uniformly distributed for M26, M9, B9, and G6210. The sensitivity analysis is conducted by setting probabilities of fire blight ranges from 0 to 100% and we consider increments of 10%. Therefore, trees replaced after fire blight are expressed in the following formula:

(5.1) $$N_{rt} = N_t \times P_i \times P(fb),$$

where N_{rt} denotes number of trees replaced per acre after fire blight, N_t denotes density (number of trees before fire blight per acre), P_i denotes a proportion of fire blight infected for a rootstock, $P(fb)$ denotes the probability of fire blight. Then we obtain revenues after fire blight in the formula:

(5.2) $$R_{fb} = N_{rt} \times Y \times P,$$

where R_{fb} denotes revenues per acre after fire blight, Y denotes yield for each technology package, P denotes price generated for each technology package.

Also, we assume the occurrence of fire blight will increase the establishment costs because growers will need to repurchase new trees in the third year; it will also decrease variable costs, pruning costs, harvest costs in subsequent years for the lost trees. Therefore, the net return of each technology package after fire blight is expressed as:

(5.3) $$VC_{fb} = VC \times (1 - \frac{N_{rt}}{N_t})$$

(5.4) $$PC_{fb} = PC \times (1 - \frac{N_{rt}}{N_t})$$

(5.5) $$HC_{fb} = HC \times (1 - \frac{N_{rt}}{N_t})$$

$$(5.6) \qquad EC_{fb} = EC \times \frac{N_{rt}}{N_t}$$

$$(5.7) \qquad NR_{fb} = R_{fb} - FC - VC_{fb} - PC_{fb} - HC_{fb} - EC_{fb},$$

where the subscript fb indicates various costs and net return after fire blight. Discounting 20 years of net returns with fire blight, an accumulated net present value distribution for each technology package after fire blight is generated. In our calculations, we obtain two accumulated net present values, one assuming no fire blight, and another assuming 100% fire blight. Then, we calculated accumulated net present values for fire blight occurring from 10% to 100% by using the formula:

$$(5.8) \qquad ANPV_{X\%fb} = ANPV_{0\%fb} \times (1 - X\%) + X\% \times ANPV_{100\%fb}$$

Where $ANPV_{X\%fb}$ denotes an accumulated net present value for fire blight occurring at X% ranging from 10% to 90% with 10% incremental. The $ANPV_{0\%fb}$ denotes an accumulated net present value for no fire blight, and $ANPV_{100\%fb}$ denotes an accumulated net present value for fire blight with 100% probability.

5.1.3 Assumption for Risk Aversion Utility Function

After generating accumulated net present values, we obtain numerical values of adopting the different technology packages. Because farmers make technology adoption decisions to maximize their utilities instead of numerical monetary returns, two expected utility functions are applied to calculate farmers' utilities. They are the constant absolute risk aversion (CARA) utility function and the constant relative risk aversion (CRRA) utility function. For the CARA utility function, distributions of accumulated net present values are assumed as normal distributions by fitting them in @Risk through applying AIC tests. Using the resulting means, variances from distributions and the range of absolute risk aversions (0.0001 to 0.001) cited from the previous literature, we calculate a certainty equivalent for each technology package, and assume the one with the largest certainty equivalent will be adopted. As for the CRRA utility function, because obtaining a closed function form for certainty equivalent is difficult, the empirical ANPV generated from the simulation work is directly used to calculate certainty equivalents under the CRRA utility function. Results will be certainty equivalents for different technology packages under a range of relative risk aversions (1.0 to 6.0) cited from the literature.

5.2 Economic Simulations of Technology Returns

5.2.1 Statistical Quality Report

Before, we conduct the economic simulations, a statistical summary of the quality report is generated. We show quality reports for Fuji at the Dressels Farm in high density systems (SA, TS) in table 5-1; for Fuji, at the Dressels Farm in low density systems (SP, VA) in table 5-2; for Gala, at the Dressels Farm in high density systems (SA, TS) in table 5-3; for Gala, at the Dressels Farm in low density systems (SP, VA) in table 5-4; for Gala, at the VandeWalle Farm in high density systems (SA, TS) in table 5-5; for Gala, at the VandeWalle Farm in low density systems (SP, VA) in table 5-6; for Honeycrisp, at the VandeWalle Farm in high density systems (SA, TS) in table 5-7; for Honeycrisp, at the VandeWalle Farm in low density systems (SP, VA) in table 5-8.

Based on tables 5-1 to 5-8, lower density systems generate higher quality fruit, and Gala performs better than Fuji and Honeycrisp. Gala trees from the VandeWalle farm perform better than Gala trees from the Dressels farm, which is in line with the work from Reig (2018) in the same locations. In high density systems, in 6 out of the 8 cases, B9 generates a larger proportion of XXFancy grade than M9, G11 and G41. As for Gala in the two farms in the SP low density system, G6210 generates a larger proportion of XXFancy grade than M26. The VA low density system, M9 generates a larger proportion of XXFancy grade than G41. As for Honeycrisp, G11 and G41 have a larger proportion in the XXFancy grade than M9 and B9 in the TS system.

5.2.2 Simulation Results for the Baseline Situation without Fire Blight

This section comprises two parts for each of the two farms. In the Dressels Farm, there are two parts for the varieties Fuji and Gala, grown in the four planting systems: SA (908 trees per acre), TS (1320 trees per acre), SP (340 trees per acre), and VA (519 trees per acre). In the VandeWalle Farm, there are two parts for the varieties Gala and Honeycrisp (HC), grown in the same four systems.

For Fuji fruit provided on the Dressels Farm, the summary statistics for the ANPV ($/acre) are shown in Table 5-9. Without fire blight, in the SA system (908 trees per acre), M9>G11>G41>B9 in terms of expected accumulated net present value (ANPV). This result is reasonable as M9 is the most popular rootstock at present, usually generates a good return, but is susceptible to fire blight. Although B9 is also resistant to fire blight, it is not as good horticulturally as G41 and M9 because of very small tree size, which is indicated by generally lower returns generated by B9. In the TS system (1320 trees per acre), G11>M9>B9>G41 in terms of expected value. In the SP system (340 trees per acre) and the VA system (519 trees per acre), Geneva rootstocks (G6210, G41) perform better than current rootstocks (M26, M9) in terms of expected value. In all, when there is no fire blight, for variety Fuji, in the higher density systems (SA, TS), M9 and G11 both perform better than B9 and G41. In lower density systems (SP, VA), G6210 and G41 perform better than M9 and M26.

For Gala provided on the Dressels Farm, the summary statistics for the ANPV ($/acre) are shown in Table 5-10. Without fire blight, for Gala variety, in the SA (908 trees per acre) planting system, G11>B9>G41>M9 in terms of expected value. In the

TS (1320 trees per acre) planting system, G11>G41>M9>B9, and G11, G41 are significantly larger than B9 and M9 in terms of expected value. In the SP system (340 trees per acre), G6210 is larger than M26 in terms of expected value. In the VA system (519 trees per acre), M9 is larger than G41 in terms of expected value. In all, without fire blight, for variety Gala, in the higher density systems, G11, B9 perform better in the SA system, G11 and G41 perform significantly better in the TS system. Compared with the variety Fuji, Geneva rootstocks seem to be better for producing Gala in the TS system. In the lower density systems, G6210 still performs better than M26 for Gala in the SP system, but M9 is better than G41 for Gala in the VA system.

Overall, on the Dressels farm, G11 performs well in the higher density systems (SA, TS) for Gala and Fuji. Rootstocks G11 and G41 perform especially well in the TS system for Gala. In the SP system, G6210 performs better than M9 for Gala and Fuji, and B9 usually generates lower returns because of its less favorable horticultural characteristics.

For Gala on the VandeValle Farm, the summary statistics for the ANPV ($/acre) are shown on the Table 5-11. Without fire blight, in the SA system (908 trees per acre), G41>M9>G11>B9 in terms of expected ANPV. This result is very different compared to Gala grown on the Dressels Farm, especially for G41. The main reason is likely that G41 for Gala in the VandeWalle Farm generates the highest price and the second largest yield. But this is only a special case as expected ANPVs of G41 in other situations are relatively low. In the TS system (1320 trees per acre), G11>B9>M9>G41 in terms of expected ANPV. In the SP system (340 trees per acre), the expected ANPV of M26 is larger than G6210, and in the VA system (519 trees per acre), the expected ANPV of G41 is larger than M9. In all, in the higher density systems, G11 and M9 performs better than B9 and G41 in general. In lower density systems, G41 and M26 perform better than M9 and G6210. Furthermore, these results are extremely different compared with Gala grown on the Dressels Farm, which is in line with earlier results (Reig, 2018). Reig (2018) found that Gala trees from the VandeWalle Farm were more productive than those from Dressels Farm, and fruit were smaller, firmer and with more red color, especially for G41, M9 grown on the SA, TS, VA systems. Reig partially explains why the overall expected ANPVs in the VandeWalle Farm are larger than the overall expected ANPVs in the Dressels Farm, and why G41 and M9 outperformed in the SA system. Moreover, it also indicates the importance of location in determining the expect ANPV for apple farms.

For Honeycrisp produced on the VandeWalle Farm, the summary statistics for the ANPV ($/acre) are shown in Table 5-12. Without fire blight, for Honeycrisp variety, in the SA (908 trees per acre) planting system, G11>M9>B9>G41 in terms of expected ANPV. In the TS (1320 trees per acre) planting system, M9>G41>G11>B9. In the SP system (340 trees per acre), M26 is larger than G6210 in terms of expected ANPV. In VA system (519 trees per acre), G41 is larger than M9 in terms of expected ANPV. In all, without fire blight, for the variety Honeycrisp, in the higher density systems, G11 and M9 perform better than B9 and G41 in general. In the lower density systems, G41 and M26 perform better than M9 and G6210. The comparative results are almost the same compared with Gala grown in the same location. The results of Honeycrisp are generally higher than Gala because of the higher prices for Honeycrisp.

Overall, in the Dressels Farm and the VandeWalle Farm, G11 generally performs well in the higher density systems (SA, TS) for the three varieties, especially for Gala in the TS system in the two locations. Furthermore, location is an important factor in determining the expected ANPV.

5.2.3 Sensitivity Analysis to consider the effects of Fire Blight

This section comprises 16 parts in two locations. As for the Dressels Farm, for Fuji and Gala varieties, four systems (SA, TS, SP, VA) are analyzed. For the VandeWalle Farm for Gala and Honeycrisp, the same four systems (SA, TS, SP, VA) are analyzed. I only focus on the Honeycrisp results here (others are in the appendix), in order to study whether Geneva rootstocks have better performance for Honeycrisp, which is the most popular cultivar. Moreover, the other results are quite similar to the analysis of Honeycrisp.

For VandeWalle Farm, Honeycrisp variety, in the SA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 5-1. This graph shows that the expected ANPV is G11>M9>B9>G41 when the probability of fire blight is 0. The expected ANPV of G11 is always the largest one as the probability of fire blight increases. But, as the probability of fire blight exceeds 35%, the expected ANPV of B9 becomes larger than the expected ANPV of M9. As the probability of fire blight exceeds 95%, the expected ANPV of G41 becomes larger than the expected ANPV of M9.

For Honeycrisp on the VandeWalle Farm, in the TS system, the sensitivity analysis for the expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 5-2. This graph shows the expected ANPV is M9>G41>G11>B9 when the probability of fire blight is 0. The expected ANPV of B9 is always the smallest as the probability of fire blight increases. As the probability of fire blight exceeds 10%, the expected ANPVs of G41 becomes larger than the expected ANPV of M9. As the probability of fire blight exceeds 13%, the expected ANPVs of G11 becomes larger than the expected ANPV of M9.

For VandeWalle Farm, Honeycrisp variety, in the SP system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 5-3. This graph shows the expected ANPV of M26 is larger than the expected ANPV of G6210 when the probability of fire blight is 0. However, as the probability of fire blight increases more than around 5%, the expected ANPV of G6210 is larger than the expected ANPV of M26.

For VandeWalle Farm, Honeycrisp variety, in the VA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 5-4. This graph shows that the expected ANPV of G41 is always larger than the expected ANPV of M9.

5.3 Risk Analysis Results

5.3.1 Baseline Certainty Equivalents for CARA and CRRA

This section includes 8 parts for each farm; each farm focuses on two varieties across the four planting systems, SA, TS, SP, VA. Each variety in specific farm and system includes two subparts. First, the calculated certainty equivalent under the CARA utility function, and second, the certainty equivalent under the CRRA utility function. I focus on the Honeycrisp results in this section, other results are in the appendix, in order to study whether Geneva rootstocks have better performance in Honeycrisp, the most popular cultivar. Moreover, the other results are almost similar to the Honeycrisp results.

On the VandeWalle Farm, the results for Honeycrisp in the SA planting system (908 trees/acre) are compared across four rootstocks, G41, G11, B9, M9 in terms of certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown in Figure 5-5. From 0.0001 to 0.0004, the order of CE is G11>M9>B9>G41, which is the same as the numerical result generated before. For the range between 0.0004 to 0.0006, the order of CE is M9>G11>B9>G41 due to the larger standard deviation of G11 compared to M9. For the range between 0.0006 to 0.001, the order of CE is M9>G11>G41>B9 because of larger standard deviation of B9 than G41. Also, for the same farm, same system and same rootstocks, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown in Figure 5-6. The results show, for Honeycrisp grown in the SA system, on the VandeWalle farm, assuming a 1 to 6 relative risk aversion parameter, the order of CE is G11>M9>B9>G41, which is the same as the numerical ANPV result and the same as the results of ARA from 0.0001 to 0.0004.

As for the TS planting system (1320 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown in Figure 5-7. From 0.0001 to 0.0004, the order of CE is M9>G41>G11>B9, which is the same as the numerical value generated before. From 0.0004 to 0.001, the order of CE is M9>G41>B9>G11 which is due to the larger standard deviation of G11 than B9. Also, for the same farm, same system and same rootstocks, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown in Figure 5-8. The results show, for Gala, growing in SA system, in the Dressels farm, from 1 to 6 relative risk aversion, the order of CE is M9>G41>G11>B9, which is the same as the numerical ANPV result and the same as the results of ARA from 0.0001 to 0.0004.

As for the SP planting system (340 trees/acre), two rootstocks, G6210, M26 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown in Figure 5-9. From 0.0001 to around 0.001, the certainty equivalent of M26 is larger than the certainty equivalent of G6210, which is the same as the numerical ANPV result. Also, for the same farm, same system and same rootstocks, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown in Figure 5-10. The results show, from 1 to 6 relative risk aversion, the order of CE is M26>G6210, which is the same as the numerical ANPV result and the same as the results of ARA.

As for the VA planting system (519 trees/acre), two rootstocks, G41, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown in Figure 5-11. From 0.0001 to around 0.001, the certainty equivalent of M9 is larger than the certainty equivalent of G41, which is different than the numerical value generated before. Also, for the same farm, same system and same rootstocks, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown in Figure 5-12. From 1 to 6, the certainty equivalent of G41 is larger than the certainty equivalent of M9, which is the same as the numerical value generated before and is different than the value of ARA.

5.3.2 Sensitivity Analysis of Fire Blight under CRRA

This section includes 8 parts for each farm; each farm focuses on two varieties across the four systems (SA, TS, SP, VA). Based on the analysis from the previous section, we use the relative risk aversion (RRA) coefficients between 1 and 6 to compare certainty equivalents under different probabilities of fire blight. I focus on the Honeycrisp results in this section, other results are in the appendix, in order to study whether Geneva rootstocks have better performance in Honeycrisp.

As for HC grown in the SA system, on the VandeWalle Farm, Figure 5-13 shows results for the certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight. The larger decreasing rate of M9 indicates its vulnerability to fire blight. The general thrust of the results do not change as RRA increases because of their similar variances. The certainty equivalent of G11 is always larger than the certainty equivalents of M9, B9 and G41. When the probability of fire blight is larger than 40%, the certainty equivalent is larger for B9 compared to M9, when the probability of fire blight is larger than 92%, the certainty equivalent is larger for G41 compared to M9.

As for the TS system, Figure 5-14 shows results for the certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight. The certainty equivalents of G11, G41 and M9 are always larger than the certainty equivalent of B9. Again, the larger decreasing slope rate of M9 indicates its vulnerability of fire blight. The general thrust of M9 and G41 does not change because of similar variances. The cross point of M9 and G11 increases due to G11 have larger standard deviation than M9. When the probability of fire blight ranges from 15% to 20%, the certainty equivalent is larger for G11 compared to M9.

As for the SP system, Figure 5-15 shows results for the certainty equivalents of G6210, M26 under different probabilities of fire blight. The certainty equivalent of M26 is larger than the certainty equivalent of G6210 at the beginning, as the probability of fire blight increases, the certainty equivalent of M26 becomes smaller than the certainty equivalent of G6210. The larger decreasing slope rate of M26 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As RRA increases, the fire blight probability of the cross point of G6210 and M26 increases. These indicates as farmer becomes more risk averse, he is less willing to change from M26 to G6210 because of smaller variances of M26. The fire blight probability to change from M26 to G6210 ranges from 5% to 10%.

As for the VA system, Figure 5-16 shows tendencies of certainty equivalents of G41, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of G41 is always larger than the certainty equivalent of M9.

Table 5-1 Fruit Grade Proportion for Fuji at Dressel Farm in High Density Systems

Fuiji	Dressel Farm	High Density	SA				TS			
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %
XXFancy										
163	116	1.03	0	0.0%	0.0%	0.1%	0.0%	0.2%	0.0%	0.1%
150	128	0.60	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
138	136	0.82	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
125	153	1.08	0	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%
113	167	0.77	0	0.1%	0.1%	0.7%	0.3%	0.6%	0.2%	0.7%
100	190	1.03	0	0.1%	0.2%	0.3%	0.3%	0.2%	0.1%	0.5%
88	215	1.07	0	0.2%	0.2%	0.6%	0.1%	0.2%	0.3%	0.9%
80	238	1.07	0	0.0%	0.2%	0.0%	0.3%	0.2%	0.3%	0.2%
72	264	1.09	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
% Total fruit			0.0%	0.4%	0.7%	1.9%	1.0%	1.4%	1.2%	2.6%
XFancy										
163	116	0.88	0.2%	0.4%	0.1%	1.3%	0.2%	0.7%	0.2%	0.7%
150	128	0.53	0.0%	0.2%	0.1%	0.2%	0.2%	0.3%	0.0%	0.3%
138	136	0.85	0.2%	0.1%	0.1%	0.1%	0.3%	0.0%	0.9%	1.0%
125	153	0.99	0.1%	0.4%	0.5%	0.5%	0.2%	0.6%	0.9%	0.1%
113	167	0.71	2.4%	2.6%	1.9%	2.0%	2.0%	3.5%	3.3%	3.4%
100	190	0.87	3.9%	2.8%	3.5%	3.3%	1.8%	1.6%	1.6%	2.6%
88	215	0.91	1.3%	2.6%	2.5%	6.5%	1.5%	1.2%	3.5%	5.0%
80	238	0.91	2.5%	0.3%	2.9%	3.3%	2.0%	1.6%	5.3%	1.4%
72	264	0.89	0.5%	0.3%	0.4%	1.2%	0.5%	0.3%	0.9%	1.1%
% Total fruit			17.2%	9.7%	12.0%	18.5%	8.7%	9.7%	16.6%	15.5%
Fancy										
163	116	0.59	0.5%	0.7%	0.1%	2.3%	0.3%	1.4%	0.2%	1.1%
150	128	0.46	0.0%	0.5%	0.5%	0.5%	0.3%	1.1%	0.0%	0.9%
138	136	0.52	0.7%	0.3%	0.4%	0.4%	0.6%	0.0%	1.9%	1.1%
125	153	0.68	0.6%	1.1%	1.9%	0.8%	0.4%	1.6%	1.1%	0.4%
113	167	0.47	6.0%	6.6%	4.3%	2.0%	4.3%	7.6%	3.7%	5.4%
100	190	0.60	9.6%	8.3%	8.5%	4.5%	4.5%	4.3%	2.8%	4.5%
88	215	0.64	3.6%	6.5%	5.1%	8.6%	5.6%	2.8%	4.6%	7.8%
80	238	0.64	3.5%	1.2%	5.3%	5.3%	5.6%	3.0%	5.5%	3.4%
72	264	0.72	1.6%	0.8%	1.7%	2.1%	1.8%	0.6%	1.5%	2.7%
% Total fruit			26.1%	26.0%	27.8%	26.6%	23.5%	22.3%	21.2%	27.2%
No.1										
163	116	0.78	0.9%	0.8%	0.1%	2.9%	0.3%	1.2%	0.1%	1.1%
150	128	0.46	0.0%	0.3%	0.7%	0.8%	0.5%	1.3%	0.0%	1.1%
138	136	0.46	1.6%	0.2%	0.3%	0.7%	1.2%	0.0%	2.8%	1.2%
125	153	0.46	1.0%	0.7%	2.2%	1.1%	0.9%	1.8%	1.2%	0.4%
113	167	0.37	5.3%	5.6%	3.9%	2.7%	4.0%	6.1%	4.0%	4.4%
100	190	0.63	9.2%	9.7%	9.0%	3.1%	5.0%	6.4%	3.8%	3.9%
88	215	0.71	4.6%	6.2%	4.9%	5.6%	6.1%	4.8%	4.6%	6.9%
80	238	0.69	2.7%	1.5%	4.5%	5.5%	5.7%	4.3%	5.1%	3.0%
72	264	0.82	2.3%	2.0%	1.7%	2.2%	2.7%	1.4%	2.1%	2.4%
% Total fruit			27.6%	27.1%	27.3%	24.5%	26.4%	27.1%	23.7%	24.4%
Utility										
163	116	0.16	2.3%	1.6%	0.1%	2.8%	0.5%	1.3%	0.0%	1.7%
150	128	0.23	0.0%	0.4%	0.5%	0.8%	1.0%	2.5%	0.0%	1.9%
138	136	0.23	4.2%	0.2%	0.2%	0.9%	2.6%	0.0%	4.4%	1.8%
125	153	0.23	2.4%	0.8%	1.5%	1.7%	1.7%	3.3%	1.6%	0.7%
113	167	0.23	4.9%	8.4%	4.1%	7.2%	5.5%	11.2%	6.2%	5.3%
100	190	0.23	10.3%	12.9%	11.2%	2.9%	8.9%	10.0%	7.4%	4.4%
88	215	0.23	4.7%	7.2%	6.5%	6.7%	9.9%	5.8%	6.4%	7.4%
80	238	0.23	2.9%	1.9%	5.3%	4.0%	7.0%	4.1%	8.0%	3.7%
72	264	0.23	3.4%	3.3%	2.8%	1.5%	3.3%	1.2%	3.3%	3.5%
% Total fruit			35.1%	36.7%	32.2%	28.5%	40.4%	39.4%	37.2%	30.2%

Table 5-2 Fruit Grade Proportion for Fuji at Dressel Farm in Low Density Systems

Fuiji	Dressel Farm	Low Density	SP		VA	
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G6210 7-year Pack-Out %	M26 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %
XXFancy						
163	116	1.03	0.0%	0.0%	0.0%	0.0%
150	128	0.60	0.0%	0.0%	0.0%	0.0%
138	136	0.82	0.1%	0.0%	0.0%	0.3%
125	153	1.08	0.1%	0.0%	0.0%	0.0%
113	167	0.77	0.3%	0.0%	0.2%	0.5%
100	190	1.03	0.5%	1.6%	0.9%	0.9%
88	215	1.07	0.7%	0.6%	0.6%	0.7%
80	238	1.07	0.3%	0.1%	0.4%	0.4%
72	264	1.09	0.0%	0.0%	0.0%	0.2%
% Total fruit			2.0%	2.3%	2.1%	2.9%
XFancy						
163	116	0.88	0.6%	0.6%	0.4%	0.5%
150	128	0.53	0.1%	0.2%	0.0%	0.2%
138	136	0.85	0.9%	0.4%	0.0%	1.9%
125	153	0.99	1.1%	1.3%	1.1%	0.9%
113	167	0.71	5.0%	3.2%	3.4%	3.9%
100	190	0.87	7.0%	11.2%	6.1%	4.7%
88	215	0.91	7.1%	4.9%	3.8%	5.0%
80	238	0.91	4.9%	2.4%	2.0%	2.8%
72	264	0.89	2.2%	2.1%	0.2%	1.4%
% Total fruit			28.9%	26.3%	17.0%	21.3%
Fancy						
163	116	0.59	0.5%	1.7%	0.7%	1.4%
150	128	0.46	0.1%	0.1%	0.0%	0.5%
138	136	0.52	1.9%	1.3%	0.0%	2.3%
125	153	0.68	2.0%	2.7%	1.7%	2.7%
113	167	0.47	5.4%	5.0%	4.9%	6.3%
100	190	0.60	5.7%	8.3%	10.5%	3.5%
88	215	0.64	5.6%	4.3%	5.3%	6.7%
80	238	0.64	3.6%	3.0%	3.4%	3.7%
72	264	0.72	2.6%	3.0%	0.4%	1.9%
% Total fruit			27.3%	29.4%	26.9%	29.1%
No.1						
163	116	0.78	0.3%	0.8%	0.5%	0.7%
150	128	0.46	0.1%	0.0%	0.0%	0.2%
138	136	0.46	0.8%	0.6%	0.0%	1.2%
125	153	0.46	0.9%	1.6%	1.4%	1.5%
113	167	0.37	3.7%	3.5%	6.4%	4.7%
100	190	0.63	7.3%	5.4%	8.4%	3.1%
88	215	0.71	4.4%	3.1%	4.7%	6.5%
80	238	0.69	2.8%	1.9%	2.6%	3.6%
72	264	0.82	2.4%	1.9%	1.0%	1.8%
% Total fruit			22.7%	18.7%	25.0%	23.3%
Utility						
163	116	0.16	0.2%	0.7%	0.2%	0.9%
150	128	0.23	0.2%	0.0%	0.0%	0.2%
138	136	0.23	0.5%	0.6%	0.0%	1.0%
125	153	0.23	0.6%	1.5%	0.4%	1.5%
113	167	0.23	2.9%	2.9%	9.4%	4.1%
100	190	0.23	9.5%	7.0%	7.8%	2.7%
88	215	0.23	2.6%	5.3%	7.8%	6.6%
80	238	0.23	1.4%	2.6%	2.4%	4.3%
72	264	0.23	1.1%	2.6%	1.0%	2.1%
% Total fruit			19.0%	23.2%	29.0%	23.4%

Table 5-3 Fruit Grade Proportion for Gala at Dressel Farm in High Density Systems

Gala	Dressel Farm	High Density	SA				TS			
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %
XXFancy										
163	116	1.03	0.6%	1.1%	1.0%	0.5%	1.5%	0.8%	1.1%	1.2%
150	128	0.60	0.1%	1.5%	0.1%	0.7%	0.8%	0.8%	0.1%	0.7%
138	136	0.82	2.6%	0.4%	1.1%	2.6%	2.2%	2.4%	1.5%	1.4%
125	153	1.08	9.2%	3.1%	1.4%	6.3%	1.4%	4.3%	2.3%	12.7%
113	167	0.77	5.8%	18.2%	8.9%	6.3%	12.7%	13.3%	9.3%	8.5%
100	190	1.03	13.7%	4.8%	15.9%	15.1%	6.7%	9.7%	20.0%	8.2%
88	215	1.07	0.1%	0.3%	0.4%	4.9%	7.6%	3.7%	0.9%	4.8%
80	238	1.07	0.0%	0.0%	0.6%	0.0%	0.8%	0.0%	0.2%	0.0%
72	264	1.09	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%
% Total fruit			32.1%	29.5%	29.5%	36.4%	33.6%	34.9%	35.3%	37.6%
XFancy										
163	116	0.88	0.4%	1.2%	0.9%	1.2%	3.0%	1.3%	1.1%	1.2%
150	128	0.53	0.4%	1.6%	0.2%	0.2%	0.9%	0.7%	0.1%	0.9%
138	136	0.85	1.5%	0.5%	2.2%	4.2%	4.4%	1.1%	2.1%	2.4%
125	153	0.99	1.2%	5.9%	2.0%	3.8%	3.0%	6.0%	2.1%	7.0%
113	167	0.71	3.1%	11.0%	9.8%	3.7%	5.4%	6.3%	10.9%	5.5%
100	190	0.87	6.4%	6.0%	11.0%	5.5%	3.6%	6.1%	6.6%	4.2%
88	215	0.91	0.5%	0.1%	0.5%	1.0%	1.7%	2.4%	1.0%	1.4%
80	238	0.91	0.0%	0.0%	0.2%	0.0%	0.1%	0.0%	0.1%	0.0%
72	264	0.89	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
% Total fruit			17.3%	26.2%	26.9%	19.5%	22.2%	23.8%	24.0%	22.5%
Fancy										
163	116	0.59	0.4%	0.9%	0.7%	1.3%	2.6%	1.1%	1.1%	1.1%
150	128	0.46	1.4%	0.5%	0.2%	0.3%	1.0%	0.5%	0.1%	0.9%
138	136	0.52	4.4%	0.4%	2.4%	4.6%	3.9%	0.7%	1.5%	2.1%
125	153	0.68	2.0%	4.5%	2.3%	3.2%	2.6%	5.2%	1.5%	5.2%
113	167	0.47	2.9%	8.2%	8.1%	2.6%	4.2%	4.3%	7.9%	4.3%
100	190	0.60	5.8%	4.2%	5.9%	5.8%	3.4%	4.2%	4.8%	2.4%
88	215	0.64	0.4%	0.0%	0.2%	0.2%	1.3%	1.8%	1.0%	0.6%
80	238	0.64	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
72	264	0.72	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
% Total fruit			17.3%	18.8%	19.9%	18.0%	19.0%	17.7%	17.9%	16.6%
No.1										
163	116	0.78	0.4%	0.4%	0.2%	0.6%	1.2%	0.4%	0.4%	0.4%
150	128	0.46	1.7%	0.4%	0.1%	0.1%	0.3%	0.2%	0.0%	0.4%
138	136	0.46	5.0%	0.2%	0.8%	1.6%	1.7%	0.3%	0.6%	0.9%
125	153	0.46	1.7%	1.8%	0.9%	1.0%	1.2%	2.0%	0.5%	2.3%
113	167	0.37	2.3%	3.3%	3.3%	2.0%	1.7%	2.0%	2.8%	2.0%
100	190	0.63	3.6%	2.3%	1.2%	4.9%	1.9%	1.8%	2.2%	0.9%
88	215	0.71	0.4%	0.0%	0.0%	0.0%	0.4%	0.6%	0.5%	0.2%
80	238	0.69	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
72	264	0.82	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% Total fruit			15.0%	8.4%	6.6%	10.3%	8.4%	7.4%	7.1%	7.0%
Utility										
163	116	0.16	0.1%	0.1%	0.1%	0.1%	0.5%	0.1%	0.1%	0.1%
150	128	0.23	1.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%
138	136	0.23	3.2%	0.1%	0.2%	0.4%	0.7%	0.1%	0.1%	0.3%
125	153	0.23	8.5%	0.5%	0.6%	0.2%	4.9%	0.7%	0.1%	5.4%
113	167	0.23	8.2%	15.9%	15.3%	14.7%	4.5%	10.4%	5.5%	10.1%
100	190	0.23	1.0%	0.5%	0.9%	0.3%	6.2%	4.4%	9.6%	0.3%
88	215	0.23	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%
80	238	0.23	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
72	264	0.23	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% Total fruit			22.2%	17.2%	17.1%	15.8%	16.9%	16.1%	15.6%	16.4%

Table 5-4 Fruit Grade Proportion for Gala at Dressel Farm in Low Density Systems

Gala	Dressel Farm	Low Density	SP		VA	
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G6210 7-year Pack-Out %	M26 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %
XXFancy						
163	116	1.03	0.9%	0.8%	0.8%	1.2%
150	128	0.60	1.3%	0.4%	0.3%	0.5%
138	136	0.82	1.3%	3.4%	1.1%	0.9%
125	153	1.08	8.3%	0.9%	4.0%	3.3%
113	167	0.77	13.4%	11.6%	18.1%	10.8%
100	190	1.03	12.5%	14.0%	3.9%	7.7%
88	215	1.07	4.3%	1.6%	0.5%	10.1%
80	238	1.07	0.2%	0.2%	0.0%	0.0%
72	264	1.09	0.0%	0.0%	0.0%	0.0%
% Total fruit			42.3%	33.0%	28.6%	34.6%
XFancy						
163	116	0.88	1.4%	0.7%	0.6%	1.1%
150	128	0.53	0.2%	0.2%	0.5%	0.6%
138	136	0.85	2.1%	1.7%	1.6%	1.4%
125	153	0.99	4.0%	3.5%	2.8%	2.3%
113	167	0.71	4.5%	8.1%	11.6%	8.5%
100	190	0.87	6.7%	9.1%	4.8%	8.1%
88	215	0.91	1.4%	2.0%	0.5%	2.9%
80	238	0.91	0.3%	0.1%	0.0%	0.0%
72	264	0.89	0.0%	0.0%	0.0%	0.0%
% Total fruit			20.5%	25.4%	22.4%	24.9%
Fancy						
163	116	0.59	1.2%	0.6%	0.5%	0.7%
150	128	0.46	0.0%	0.0%	1.0%	0.5%
138	136	0.52	2.0%	1.6%	2.6%	1.9%
125	153	0.68	3.7%	4.0%	2.9%	2.4%
113	167	0.47	3.3%	5.9%	10.1%	6.4%
100	190	0.60	5.1%	5.4%	3.8%	5.4%
88	215	0.64	0.9%	1.4%	0.4%	0.6%
80	238	0.64	0.3%	0.0%	0.0%	0.0%
72	264	0.72	0.0%	0.0%	0.0%	0.0%
% Total fruit			16.5%	18.9%	21.3%	17.8%
No.1						
163	116	0.78	0.3%	0.3%	0.2%	0.2%
150	128	0.46	0.0%	0.0%	0.7%	0.1%
138	136	0.46	0.5%	0.9%	1.9%	0.8%
125	153	0.46	1.2%	2.2%	1.7%	1.0%
113	167	0.37	1.1%	1.7%	4.9%	3.0%
100	190	0.63	1.3%	1.5%	1.5%	1.6%
88	215	0.71	0.2%	0.2%	0.1%	0.2%
80	238	0.69	0.1%	0.0%	0.0%	0.0%
72	264	0.82	0.0%	0.0%	0.0%	0.0%
% Total fruit			4.8%	6.8%	11.1%	7.0%
Utility						
163	116	0.16	0.1%	0.1%	0.1%	0.1%
150	128	0.23	0.0%	0.0%	0.3%	0.0%
138	136	0.23	0.1%	0.3%	0.6%	0.1%
125	153	0.23	5.1%	0.8%	0.3%	0.2%
113	167	0.23	5.7%	14.4%	6.9%	14.3%
100	190	0.23	4.9%	0.3%	8.4%	0.6%
88	215	0.23	0.1%	0.0%	0.0%	0.3%
80	238	0.23	0.0%	0.0%	0.0%	0.0%
72	264	0.23	0.0%	0.0%	0.0%	0.0%
% Total fruit			15.9%	15.9%	16.5%	15.7%

Table 5-5 Fruit Grade Proportion for Gala at VandeWalle Farm in high Density Systems

Gala	VandeWalle Farm	High Density	SA				TS			
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %
XXFancy										
163	116	1.03	0.6%	0.9%	2.1%	0.7%	6.0%	14.3%	13.7%	0.2%
150	128	0.60	0.5%	0.0%	0.0%	0.2%	2.0%	7.4%	5.3%	0.0%
138	136	0.82	0.7%	0.0%	5.3%	3.2%	17.2%	9.7%	1.8%	0.7%
125	153	1.08	6.9%	0.0%	6.3%	5.9%	7.8%	8.0%	5.7%	0.7%
113	167	0.77	26.8%	0.0%	0.2%	29.4%	7.2%	13.6%	7.3%	3.6%
100	190	1.03	20.4%	0.9%	0.0%	22.5%	5.4%	0.0%	11.1%	12.0%
88	215	1.07	0.7%	4.3%	7.9%	1.1%	7.9%	0.1%	2.2%	23.4%
80	238	1.07	0.4%	33.7%	20.2%	0.0%	5.3%	0.0%	6.1%	18.2%
72	264	1.09	0.5%	28.0%	24.6%	2.8%	3.1%	0.0%	4.7%	6.1%
% Total fruit			57.4%	67.9%	66.7%	65.8%	61.9%	53.0%	57.9%	65.0%
XFancy										
163	116	0.88	0.3%	0.2%	2.1%	0.2%	0.6%	9.7%	4.7%	0.1%
150	128	0.53	0.2%	0.0%	0.0%	0.1%	0.2%	4.7%	1.6%	0.0%
138	136	0.85	0.3%	0.0%	2.5%	1.5%	1.3%	4.7%	2.1%	0.1%
125	153	0.99	1.3%	0.0%	1.7%	1.3%	0.8%	4.7%	1.1%	0.1%
113	167	0.71	7.2%	0.1%	0.0%	10.8%	1.1%	2.7%	0.9%	1.2%
100	190	0.87	10.1%	0.4%	0.0%	5.6%	3.0%	0.0%	5.7%	4.3%
88	215	0.91	0.6%	1.4%	1.1%	0.4%	5.1%	0.1%	3.3%	7.4%
80	238	0.91	1.4%	8.7%	8.9%	0.0%	3.6%	0.0%	3.3%	7.7%
72	264	0.89	2.0%	10.6%	3.7%	0.3%	1.9%	0.0%	1.7%	1.4%
% Total fruit			23.9%	21.2%	19.9%	20.1%	17.6%	26.4%	24.3%	22.2%
Fancy										
163	116	0.59	0.2%	0.0%	1.6%	0.0%	1.4%	5.1%	2.8%	0.0%
150	128	0.46	0.1%	0.0%	0.0%	0.0%	0.1%	2.1%	1.2%	0.0%
138	136	0.52	0.1%	0.0%	1.9%	0.6%	2.7%	4.3%	1.8%	0.0%
125	153	0.68	0.6%	0.0%	1.3%	0.7%	1.1%	1.6%	0.3%	0.0%
113	167	0.47	2.6%	0.1%	0.0%	3.3%	0.6%	1.7%	0.6%	0.7%
100	190	0.60	4.4%	0.2%	0.0%	3.6%	1.7%	0.0%	3.6%	2.2%
88	215	0.64	0.4%	0.3%	0.2%	0.4%	1.6%	0.0%	1.8%	2.8%
80	238	0.64	1.4%	3.4%	2.2%	0.0%	1.5%	0.0%	1.8%	2.8%
72	264	0.72	2.0%	4.3%	1.0%	0.4%	0.6%	0.0%	0.3%	0.4%
% Total fruit			11.9%	8.3%	8.2%	9.0%	11.2%	14.9%	14.3%	9.0%
No.1										
163	116	0.78	0.1%	0.0%	1.1%	0.0%	1.1%	1.4%	0.3%	0.0%
150	128	0.46	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.1%	0.0%
138	136	0.46	0.0%	0.0%	1.2%	0.3%	2.1%	1.6%	0.4%	0.0%
125	153	0.46	0.1%	0.0%	0.7%	0.3%	0.8%	0.3%	0.0%	0.0%
113	167	0.37	0.6%	0.0%	0.0%	1.5%	0.1%	0.2%	0.0%	0.3%
100	190	0.63	1.6%	0.1%	0.0%	1.6%	0.9%	0.0%	0.8%	0.8%
88	215	0.71	0.2%	0.0%	0.0%	0.1%	0.1%	0.0%	0.5%	0.8%
80	238	0.69	1.2%	0.6%	0.3%	0.0%	0.3%	0.0%	0.5%	0.6%
72	264	0.82	1.6%	1.1%	0.1%	0.0%	0.2%	0.0%	0.1%	0.1%
% Total fruit			5.5%	1.7%	3.3%	3.8%	5.5%	4.1%	2.7%	2.7%
Utility										
163	116	0.16	0.0%	0.0%	0.4%	0.0%	0.7%	0.6%	0.2%	0.0%
150	128	0.23	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
138	136	0.23	0.0%	0.0%	0.4%	0.1%	1.3%	0.6%	0.1%	0.0%
125	153	0.23	0.1%	0.0%	0.2%	0.1%	0.5%	0.1%	0.0%	0.0%
113	167	0.23	0.2%	0.0%	0.0%	0.5%	0.1%	0.2%	0.0%	0.1%
100	190	0.23	0.4%	0.0%	0.0%	0.5%	0.5%	0.0%	0.2%	0.3%
88	215	0.23	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.4%
80	238	0.23	0.4%	0.4%	0.4%	0.0%	0.3%	0.0%	0.1%	0.3%
72	264	0.23	0.6%	0.5%	0.5%	0.0%	0.2%	0.0%	0.0%	0.1%
% Total fruit			1.7%	0.9%	2.0%	1.2%	3.8%	1.6%	0.8%	1.2%

Table 5-6 Fruit Grade Proportion for Gala at VandeWalle Farm in Low Density Systems

Gala	VandeWalle Farm	Low Density	SP		VA	
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G6210 7-year Pack-Out %	M26 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %
XXFancy						
163	116	1.03	24.2%	8.6%	4.6%	0.9%
150	128	0.60	7.4%	3.7%	0.4%	0.0%
138	136	0.82	22.8%	21.1%	5.2%	0.2%
125	153	1.08	18.4%	6.4%	6.8%	11.2%
113	167	0.77	0.0%	6.8%	9.9%	41.6%
100	190	1.03	0.0%	12.6%	14.9%	12.7%
88	215	1.07	0.0%	8.6%	5.4%	0.0%
80	238	1.07	0.0%	3.6%	10.8%	0.0%
72	264	1.09	0.8%	1.2%	7.6%	0.0%
% Total fruit			73.7%	72.6%	65.6%	66.6%
XFancy						
163	116	0.88	8.9%	3.1%	2.0%	0.4%
150	128	0.53	2.1%	1.7%	0.1%	0.0%
138	136	0.85	6.3%	4.8%	1.7%	0.2%
125	153	0.99	3.5%	1.0%	1.7%	3.9%
113	167	0.71	0.0%	0.5%	4.0%	15.3%
100	190	0.87	0.0%	4.2%	4.6%	3.4%
88	215	0.91	0.0%	0.6%	1.8%	0.0%
80	238	0.91	0.0%	2.6%	6.4%	0.0%
72	264	0.89	0.2%	0.5%	2.4%	0.0%
% Total fruit			21.0%	19.0%	24.7%	23.2%
Fancy						
163	116	0.59	1.8%	0.5%	0.5%	0.1%
150	128	0.46	0.3%	0.6%	0.1%	0.0%
138	136	0.52	1.1%	1.2%	0.3%	0.0%
125	153	0.68	0.5%	0.1%	0.7%	0.8%
113	167	0.47	0.0%	0.1%	2.1%	4.7%
100	190	0.60	0.0%	1.9%	1.7%	1.4%
88	215	0.64	0.0%	0.1%	0.6%	0.0%
80	238	0.64	0.0%	1.6%	2.1%	0.0%
72	264	0.72	0.0%	0.1%	0.3%	0.0%
% Total fruit			3.7%	6.3%	8.2%	7.1%
No.1						
163	116	0.78	0.7%	0.0%	0.1%	0.0%
150	128	0.46	0.1%	0.0%	0.0%	0.0%
138	136	0.46	0.4%	0.0%	0.1%	0.0%
125	153	0.46	0.2%	0.0%	0.1%	0.3%
113	167	0.37	0.0%	0.0%	0.1%	1.7%
100	190	0.63	0.0%	0.9%	0.2%	0.4%
88	215	0.71	0.0%	0.0%	0.0%	0.0%
80	238	0.69	0.0%	0.8%	0.3%	0.0%
72	264	0.82	0.0%	0.1%	0.1%	0.0%
% Total fruit			1.3%	1.7%	1.0%	2.5%
Utility						
163	116	0.16	0.1%	0.0%	0.0%	0.0%
150	128	0.23	0.0%	0.0%	0.0%	0.0%
138	136	0.23	0.1%	0.0%	0.1%	0.0%
125	153	0.23	0.1%	0.0%	0.1%	0.1%
113	167	0.23	0.0%	0.0%	0.0%	0.4%
100	190	0.23	0.0%	0.1%	0.1%	0.1%
88	215	0.23	0.0%	0.1%	0.0%	0.0%
80	238	0.23	0.0%	0.1%	0.1%	0.0%
72	264	0.23	0.0%	0.0%	0.0%	0.0%
% Total fruit			0.3%	0.4%	0.5%	0.7%

Table 5-7 Fruit Grade Proportion for Honeycrisp at VandeWalle Farm in High Density Systems

HC	VandeWalle Farm	High Density	SA				TS			
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %	G11 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %	B9 7-year Pack-Out %
XXFancy										
163	116	1.03	0.1%	1.3%	1.8%	0.1%	0.7%	0.0%	7.9%	3.7%
150	128	0.60	0.0%	2.1%	1.9%	0.0%	0.1%	0.0%	0.6%	1.4%
138	136	0.82	0.0%	3.0%	5.3%	0.1%	1.3%	0.1%	0.4%	3.2%
125	153	1.08	0.3%	5.3%	2.6%	0.0%	3.9%	0.1%	0.1%	4.9%
113	167	0.77	0.4%	3.4%	0.7%	0.6%	0.9%	0.4%	0.2%	1.0%
100	190	1.03	1.0%	0.0%	0.0%	0.5%	2.0%	4.4%	0.0%	0.0%
88	215	1.07	1.3%	0.0%	0.2%	1.5%	4.3%	1.9%	1.1%	0.0%
80	238	1.07	1.5%	0.0%	0.3%	4.0%	2.6%	4.9%	1.5%	0.0%
72	264	1.09	11.7%	0.0%	0.3%	9.6%	1.7%	5.9%	1.2%	0.0%
% Total fruit			16.3%	15.2%	13.1%	16.3%	17.6%	17.7%	13.1%	14.2%
XFancy										
163	116	0.88	0.3%	1.7%	2.4%	0.3%	1.3%	0.1%	22.2%	7.1%
150	128	0.53	0.0%	4.6%	4.1%	0.0%	0.1%	0.0%	1.4%	3.4%
138	136	0.85	0.0%	7.3%	10.0%	0.2%	7.0%	0.2%	1.1%	9.6%
125	153	0.99	0.5%	11.9%	8.6%	0.0%	7.2%	0.1%	0.1%	12.0%
113	167	0.71	0.9%	5.5%	3.8%	0.9%	2.1%	0.8%	0.4%	3.1%
100	190	0.87	1.7%	0.0%	0.0%	1.8%	2.8%	7.3%	0.2%	0.0%
88	215	0.91	2.5%	0.0%	1.2%	3.4%	6.1%	4.7%	3.6%	0.0%
80	238	0.91	4.0%	0.0%	3.1%	8.2%	4.0%	9.2%	4.3%	0.0%
72	264	0.89	26.8%	0.0%	3.6%	25.7%	5.1%	6.9%	2.3%	0.0%
% Total fruit			42.2%	31.0%	36.8%	40.5%	35.7%	29.3%	35.7%	35.3%
Fancy										
163	116	0.59	0.2%	1.1%	1.0%	0.2%	0.6%	0.2%	12.4%	4.2%
150	128	0.46	0.0%	2.6%	2.3%	0.0%	0.1%	0.0%	0.9%	1.8%
138	136	0.52	0.0%	3.0%	6.3%	0.1%	3.2%	0.1%	0.7%	8.1%
125	153	0.68	0.5%	6.8%	4.1%	0.0%	3.2%	0.1%	0.1%	7.8%
113	167	0.47	0.8%	4.6%	2.6%	0.5%	0.9%	0.5%	0.2%	2.8%
100	190	0.60	0.9%	0.0%	0.0%	1.4%	1.5%	4.4%	0.2%	0.0%
88	215	0.64	2.0%	0.0%	0.7%	1.8%	3.3%	4.3%	3.4%	0.0%
80	238	0.64	2.4%	0.0%	2.3%	4.1%	3.3%	8.0%	3.8%	0.0%
72	264	0.72	13.8%	0.0%	2.8%	15.7%	2.8%	3.6%	1.0%	0.0%
% Total fruit			20.6%	18.0%	22.2%	23.7%	18.9%	21.2%	22.8%	24.7%
No.1										
163	116	0.78	0.2%	1.3%	0.9%	0.1%	0.7%	0.1%	7.7%	1.9%
150	128	0.46	0.0%	1.8%	0.7%	0.0%	0.0%	0.0%	0.6%	0.8%
138	136	0.46	0.1%	3.6%	3.7%	0.0%	1.5%	0.1%	0.7%	4.1%
125	153	0.46	0.9%	8.9%	1.4%	0.0%	3.6%	0.1%	0.0%	3.8%
113	167	0.37	1.1%	2.4%	1.1%	0.1%	0.5%	0.4%	0.1%	1.7%
100	190	0.63	0.6%	0.1%	0.0%	0.5%	1.7%	3.7%	0.1%	0.0%
88	215	0.71	1.4%	0.0%	0.2%	0.6%	3.0%	3.2%	1.5%	0.0%
80	238	0.69	1.3%	0.0%	1.4%	1.0%	3.0%	6.1%	1.7%	0.0%
72	264	0.82	7.9%	0.0%	1.8%	8.3%	1.9%	2.7%	0.7%	0.0%
% Total fruit			13.4%	18.1%	11.1%	10.7%	16.0%	16.6%	13.1%	12.3%
Utility										
163	116	0.16	0.2%	0.9%	0.6%	0.1%	0.3%	0.2%	11.3%	2.1%
150	128	0.23	0.0%	6.4%	0.8%	0.0%	0.0%	0.0%	0.9%	0.7%
138	136	0.23	0.3%	1.4%	4.3%	0.0%	0.9%	0.3%	2.3%	4.8%
125	153	0.23	4.1%	2.9%	1.2%	0.0%	1.7%	0.1%	0.0%	3.7%
113	167	0.23	4.8%	6.1%	1.4%	0.1%	0.3%	0.3%	0.0%	2.3%
100	190	0.23	0.1%	0.0%	0.0%	0.4%	0.7%	3.2%	0.0%	0.0%
88	215	0.23	0.4%	0.0%	0.2%	0.2%	1.8%	3.6%	0.3%	0.0%
80	238	0.23	0.5%	0.0%	3.5%	0.9%	4.0%	5.7%	0.4%	0.0%
72	264	0.23	2.5%	0.0%	4.9%	7.1%	2.2%	1.8%	0.2%	0.0%
% Total fruit			13.0%	17.6%	16.8%	8.8%	11.9%	15.2%	15.4%	13.6%

Table 5-8 Fruit Grade Proportion for Honeycrisp at VandeWalle Farm in Low Density Systems

HC	VandeWalle Farm	Low Density	SP		VA	
# Fruit per box (unit)	Average fruit weight (g)	$ per unit (7 year average)	G6210 7-year Pack-Out %	M26 7-year Pack-Out %	G41 7-year Pack-Out %	M9 7-year Pack-Out %
XXFancy						
163	116	1.03	0.1%	1.3%	0.0%	14.2%
150	128	0.60	0.0%	0.0%	0.1%	1.2%
138	136	0.82	0.2%	3.1%	3.2%	0.1%
125	153	1.08	0.1%	8.3%	4.0%	0.0%
113	167	0.77	0.2%	1.9%	5.0%	0.0%
100	190	1.03	2.4%	0.5%	4.1%	0.0%
88	215	1.07	2.6%	4.2%	1.3%	0.0%
80	238	1.07	4.3%	13.0%	0.2%	0.0%
72	264	1.09	21.8%	9.7%	0.1%	0.0%
% Total fruit			31.8%	41.9%	18.0%	15.5%
XFancy						
163	116	0.88	0.2%	1.5%	0.0%	35.1%
150	128	0.53	0.0%	0.0%	0.2%	1.9%
138	136	0.85	0.3%	2.2%	5.4%	0.8%
125	153	0.99	0.1%	8.6%	7.2%	0.0%
113	167	0.71	0.3%	1.4%	13.7%	0.0%
100	190	0.87	1.4%	0.3%	7.7%	0.0%
88	215	0.91	2.8%	3.0%	2.4%	0.0%
80	238	0.91	5.0%	8.7%	0.4%	0.0%
72	264	0.89	21.9%	8.8%	0.3%	0.0%
% Total fruit			31.9%	34.4%	37.2%	37.8%
Fancy						
163	116	0.59	0.1%	0.6%	0.0%	18.1%
150	128	0.46	0.0%	0.0%	0.0%	1.0%
138	136	0.52	0.0%	0.8%	1.6%	0.5%
125	153	0.68	0.1%	3.5%	2.8%	0.0%
113	167	0.47	0.0%	0.6%	8.8%	0.0%
100	190	0.60	0.7%	0.0%	3.6%	0.0%
88	215	0.64	1.6%	0.5%	1.4%	0.0%
80	238	0.64	3.5%	1.8%	0.3%	0.0%
72	264	0.72	10.3%	2.7%	0.2%	0.0%
% Total fruit			16.4%	10.7%	18.7%	19.6%
No.1						
163	116	0.78	0.0%	0.4%	0.0%	11.4%
150	128	0.46	0.0%	0.0%	0.0%	0.6%
138	136	0.46	0.0%	0.4%	1.3%	0.2%
125	153	0.46	0.0%	2.2%	1.6%	0.0%
113	167	0.37	0.0%	0.6%	4.4%	0.0%
100	190	0.63	0.4%	0.0%	2.4%	0.0%
88	215	0.71	0.6%	0.1%	0.7%	0.0%
80	238	0.69	1.7%	0.2%	0.1%	0.0%
72	264	0.82	5.9%	0.5%	0.1%	0.0%
% Total fruit			8.7%	4.5%	10.6%	12.2%
Utility						
163	116	0.16	0.0%	0.8%	0.0%	13.4%
150	128	0.23	0.0%	0.0%	0.0%	1.3%
138	136	0.23	0.0%	0.7%	0.5%	0.2%
125	153	0.23	0.0%	4.9%	1.1%	0.0%
113	167	0.23	0.0%	1.8%	8.7%	0.0%
100	190	0.23	1.2%	0.0%	4.3%	0.0%
88	215	0.23	0.7%	0.0%	0.5%	0.0%
80	238	0.23	1.8%	0.1%	0.1%	0.0%
72	264	0.23	7.5%	0.2%	0.3%	0.0%
% Total fruit			11.2%	8.6%	15.5%	15.0%

Table 5-9 ANPV distributions for Fuiji at the Dressel Farm

	Technology Package							Distribution Percentile	
Location	Variety	System	Rootstock	Expected Value	Standard Deviation	Median	Skewness	5th	95th
Dressel Farm	Fuji	SA(908)	G41	37,986.32	8,976.11	37,131.75	0.42	24,861.16	54,574.39
Dressel Farm	Fuji	SA(908)	G11	47,705.96	6,043.36	47,705.96	0.10	38,442.72	58,034.51
Dressel Farm	Fuji	SA(908)	B9	37,865.94	4,844.73	37,579.88	0.43	30,728.12	45,913.05
Dressel Farm	Fuji	SA(908)	M9	51,800.01	7,668.99	51,504.80	0.14	39,195.23	65,132.17
Dressel Farm	Fuji	TS(1320)	G41	34,328.78	4,765.70	34,010.52	0.19	26,953.62	41,914.99
Dressel Farm	Fuji	TS(1320)	G11	65,066.98	4,923.68	64,600.98	0.19	57,104.02	72,834.11
Dressel Farm	Fuji	TS(1320)	B9	35,537.16	4,969.97	35,494.19	0.20	27,882.57	44,377.93
Dressel Farm	Fuji	TS(1320)	M9	47,739.00	6,449.36	47,124.07	0.29	37,831.04	58,759.47
Dressel Farm	Fuji	SP(340)	G6210	42,380.73	5,077.79	42,328.96	-0.08	33,848.56	50,413.98
Dressel Farm	Fuji	SP(340)	M26	28,469.36	5,078.98	28,843.50	-0.03	19,723.64	36,498.16
Dressel Farm	Fuji	VA(519)	G41	44,142.83	7,042.64	44,018.09	0.08	32,632.40	55,779.33
Dressel Farm	Fuji	VA(519)	M9	39,679.14	6,266.01	39,756.77	0.00	29,113.64	50,322.45

Table 5-10 ANPV distributions for Gala at the Dressel Farm

	Technology Package							Distribution Percentile	
Location	Variety	System	Rootstock	Expected Value	Standard Deviation	Median	Skewness	5th	95th
Dressel Farm	Gala	SA(908)	G41	41,308.42	5,820.57	41,078.41	0.56	31,835.13	51,997.11
Dressel Farm	Gala	SA(908)	G11	56,467.21	11,219.14	56,412.16	0.28	38,866.52	76,140.38
Dressel Farm	Gala	SA(908)	B9	46,012.90	7,205.46	45,750.28	0.29	35,105.69	58,232.52
Dressel Farm	Gala	SA(908)	M9	35,255.07	6,605.41	35,196.07	0.27	25,170.33	46,841.17
Dressel Farm	Gala	TS(1320)	G41	100,047.68	11,775.81	99,694.32	0.47	82,292.34	119,793.71
Dressel Farm	Gala	TS(1320)	G11	100,729.93	11,975.42	100,340.52	0.03	80,112.75	121,305.20
Dressel Farm	Gala	TS(1320)	B9	53,478.21	7,057.06	53,180.44	0.18	42,555.86	65,423.65
Dressel Farm	Gala	TS(1320)	M9	66,524.39	8,009.49	66,038.95	0.31	54,393.28	79,855.15
Dressel Farm	Gala	SP(340)	G6210	31,144.66	5,325.46	30,669.95	0.21	22,744.32	40,408.88
Dressel Farm	Gala	SP(340)	M26	21,259.64	5,017.26	20,792.75	0.52	13,888.63	29,746.29
Dressel Farm	Gala	VA(519)	G41	15,788.08	3,731.78	15,667.02	0.10	9,657.52	22,144.87
Dressel Farm	Gala	VA(519)	M9	35,089.05	6,502.96	34,808.84	0.25	25,079.73	46,058.13

Table 5-11 ANPV distributions for Gala at the VandeWalle Farm

Location	Technology Package			Expected Value	Standard Deviation	Median	Skewness	Distribution Percentile	
	Variety	System	Rootstock					5th	95th
VandeWalle Farm	Gala	SA(908)	G41	198,199.78	15,184.31	198.240.42	-0.01	172,442.20	222,958.47
VandeWalle Farm	Gala	SA(908)	G11	113,915.11	13,524.66	114,116.73	0.09	91,807.21	136,381.31
VandeWalle Farm	Gala	SA(908)	B9	101,956.17	10,681.00	101,789.97	0.12	84,442.06	119,664.48
VandeWalle Farm	Gala	SA(908)	M9	192,921.70	10,101.98	192,494.52	0.23	177,003.73	210,376.86
VandeWalle Farm	Gala	TS(1320)	G41	153,796.20	14,484.61	154,172.85	0.07	130,293.18	177,941.64
VandeWalle Farm	Gala	TS(1320)	G11	165,082.12	9,962.27	164,438.03	0.18	149,571.31	182,929.37
VandeWalle Farm	Gala	TS(1320)	B9	162,904.19	14,166.18	163,041.33	0.05	138,954.65	187,131.38
VandeWalle Farm	Gala	TS(1320)	M9	156,138.13	13,726.11	155,807.91	0.10	134,569.10	178,015.30
VandeWalle Farm	Gala	SP(340)	G6210	51,361.62	5,873.46	51,136.99	0.01	41,616.84	61,244.43
VandeWalle Farm	Gala	SP(340)	M26	55,534.97	7,511.13	54,893.48	0.25	43,912.85	69,372.00
VandeWalle Farm	Gala	VA(519)	G41	101,804.28	10,584.20	101,113.05	0.07	83,794.32	119,382.02
VandeWalle Farm	Gala	VA(519)	M9	89,681.81	10,602.74	89,373.03	0.04	71,332.03	107,444.00

Table 5-12 ANPV distributions for Honeycrisp at the VandeWalle Farm

	Technology Package							Distribution Percentile	
Location	Variety	System	Rootstock	Expected Value	Standard Deviation	Median	Skewness	5th	95th
VandeWalle Farm	HC	SA(908)	G41	167,253.35	11,534.84	167,521.12	-0.03	147,891.05	185,858.48
VandeWalle Farm	HC	SA(908)	G11	238.692.2	15,229.01	238,473.77	0.10	212,954.78	263,713.91
VandeWalle Farm	HC	SA(908)	B9	204,531.25	16,043.99	204,062.89	0.17	179,301.41	232,421.63
VandeWalle Farm	HC	SA(908)	M9	226,213.97	12,928.33	225,933.01	0.15	206,362.60	247,554.70
VandeWalle Farm	HC	TS(1320)	G41	282,962.79	14,331.59	283,050.74	0.03	259,394.84	307,208.98
VandeWalle Farm	HC	TS(1320)	G11	281,660.41	25,085.34	280,575.59	0.18	238,880.47	325,167.55
VandeWalle Farm	HC	TS(1320)	B9	217,234.19	17,695.66	216,791.27	0.05	189,427.19	246,701.28
VandeWalle Farm	HC	TS(1320)	M9	288,430.83	10,430.96	287,581.50	0.28	271,919.39	307,386.94
VandeWalle Farm	HC	SP(340)	G6210	166,631.27	13,898.67	144,197.78	0.31	123,771.42	170,760.01
VandeWalle Farm	HC	SP(340)	M26	159,504.28	12,182.30	146,485.57	0.24	127,595.29	166,794.25
VandeWalle Farm	HC	VA(519)	G41	166,631.27	20,351.53	164,931.96	0.38	135,636.55	203,306.21
VandeWalle Farm	HC	VA(519)	M9	159,504.28	14,298.16	157,361.49	0.47	139,006.96	186,922.69

FIGURE

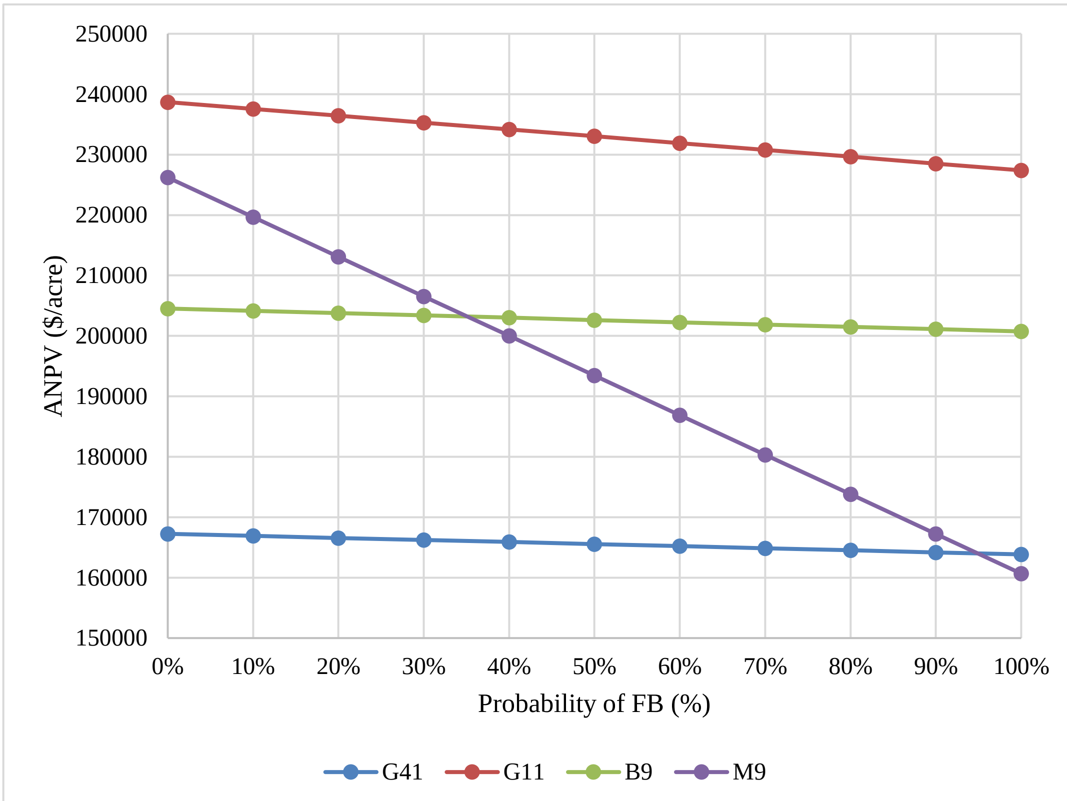

Figure 5-1 ANPV for HC, SA for Different Probabilities of Fire Blight, VandeWalle Farm

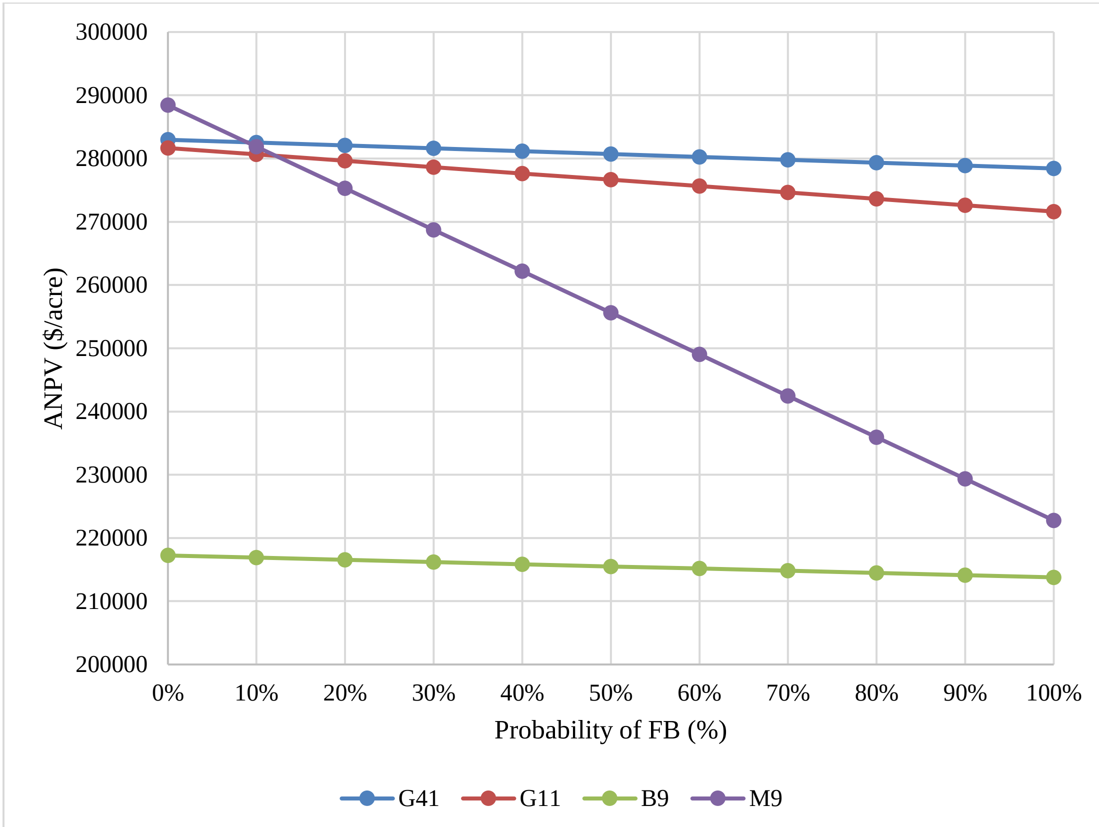

Figure 5-2 ANPV for HC, TS for Different Probabilities of Fire Blight, VandeWalle Farm

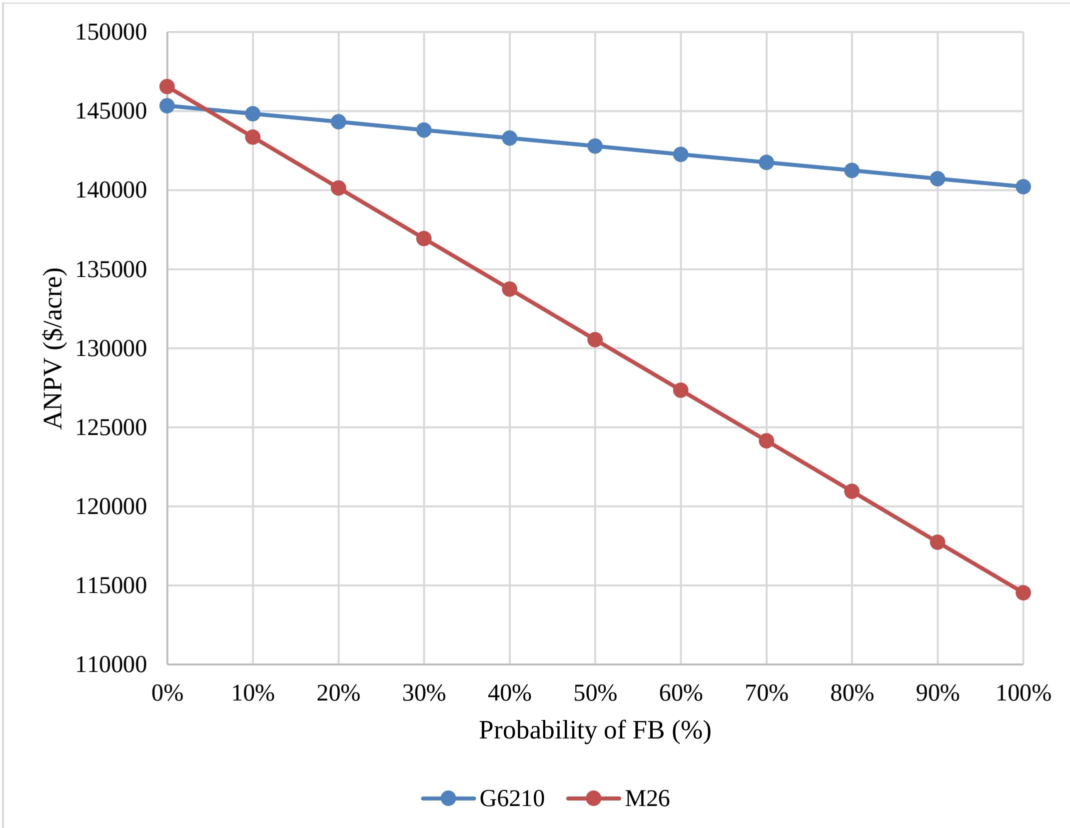

Figure 5-3 ANPV for HC, SP for Different Probabilities of Fire Blight, VandeWalle Farm

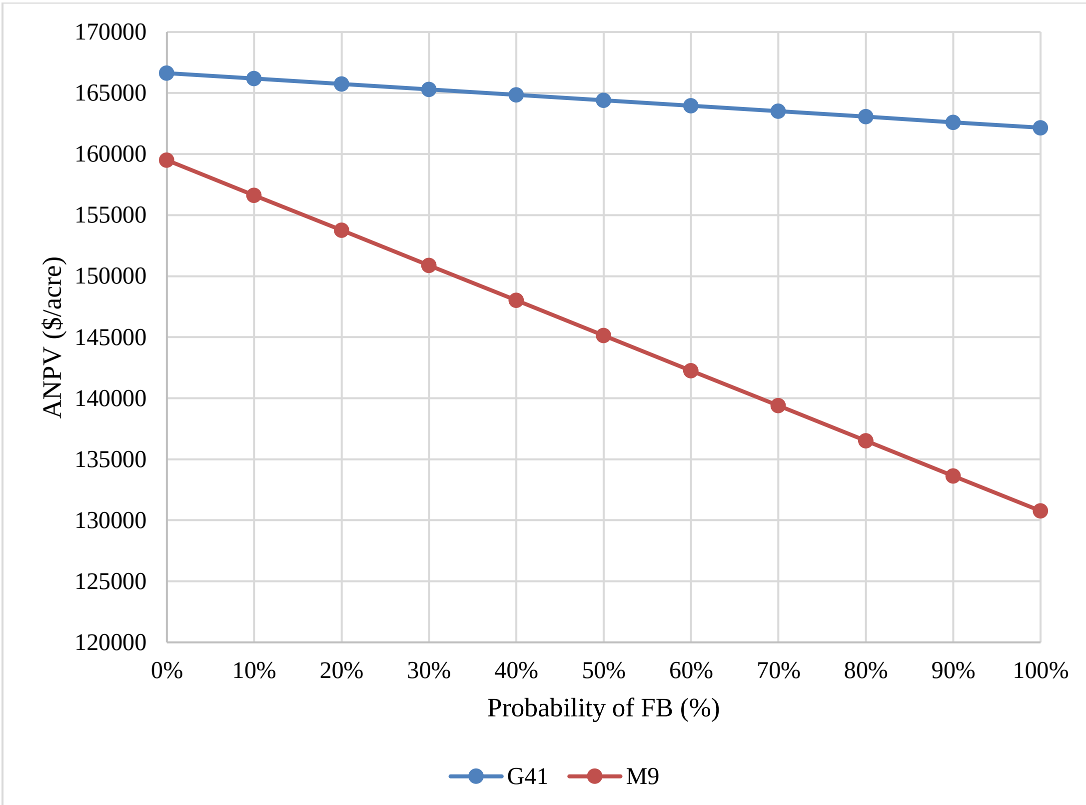

Figure 5-4 ANPV for HC, VA for Different Probabilities of Fire Blight, VandeWalle Farm

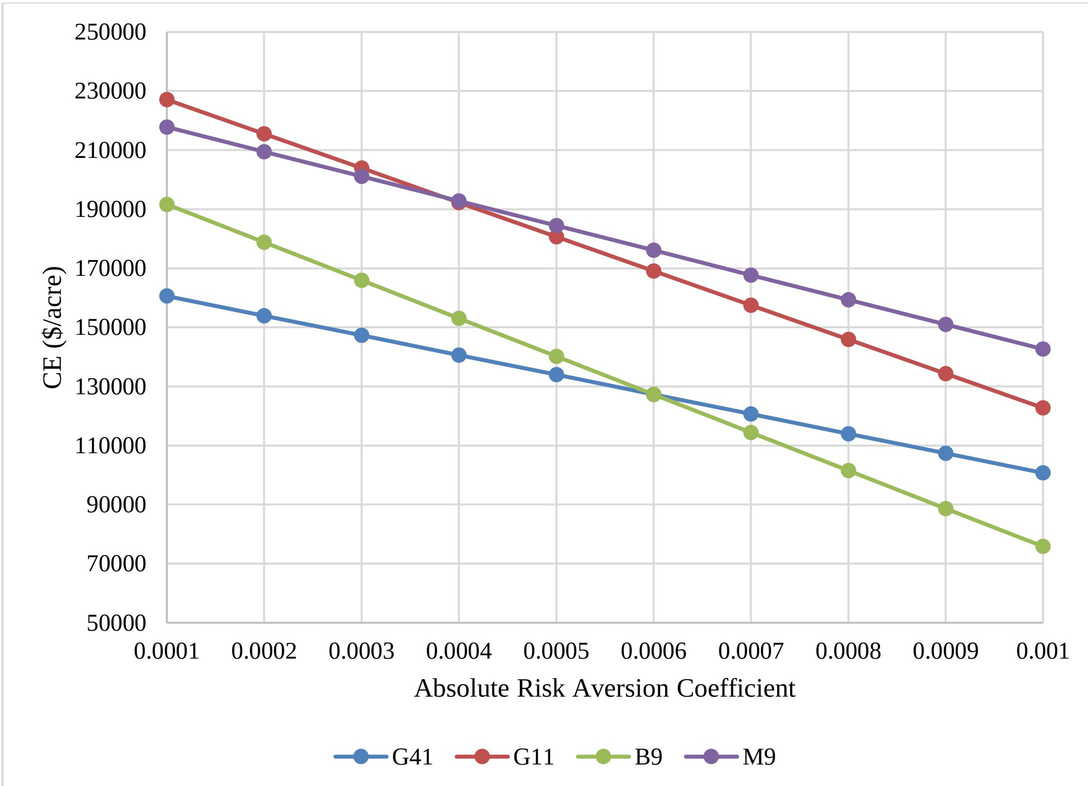

Figure 5-5 Certainty Equivalent under Different CARA for HC, SA System, VandeWalle Farm

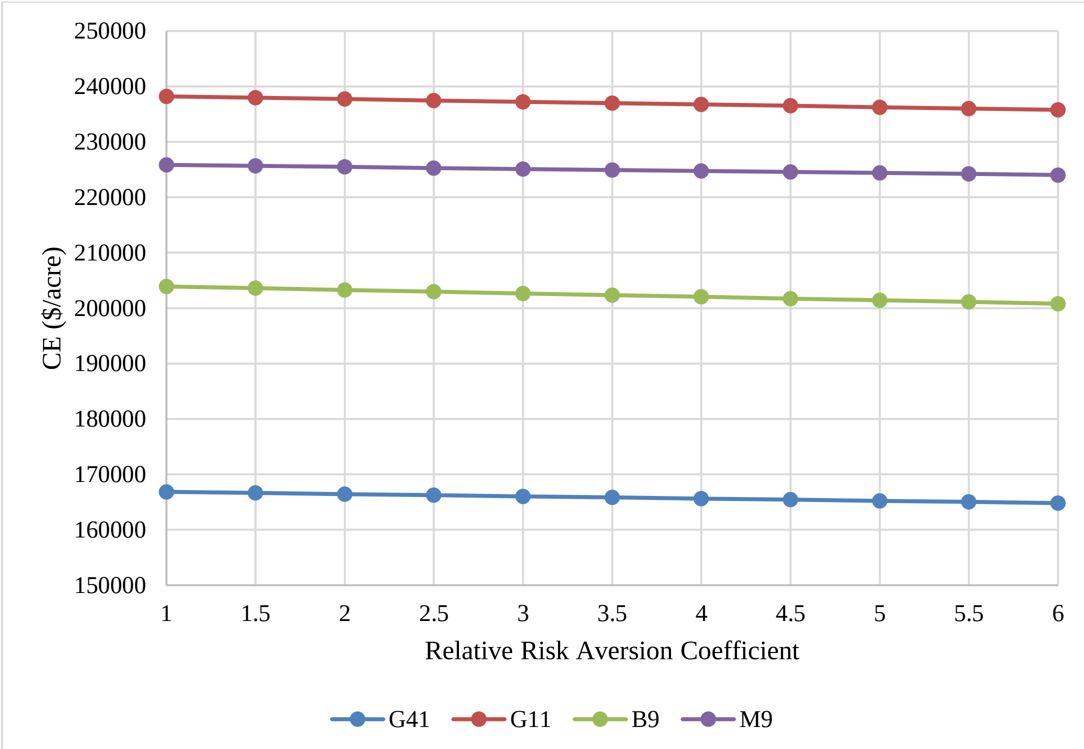

Figure 5-6 Certainty Equivalent under Different CRRA for HC, SA System, VandeWalle Farm

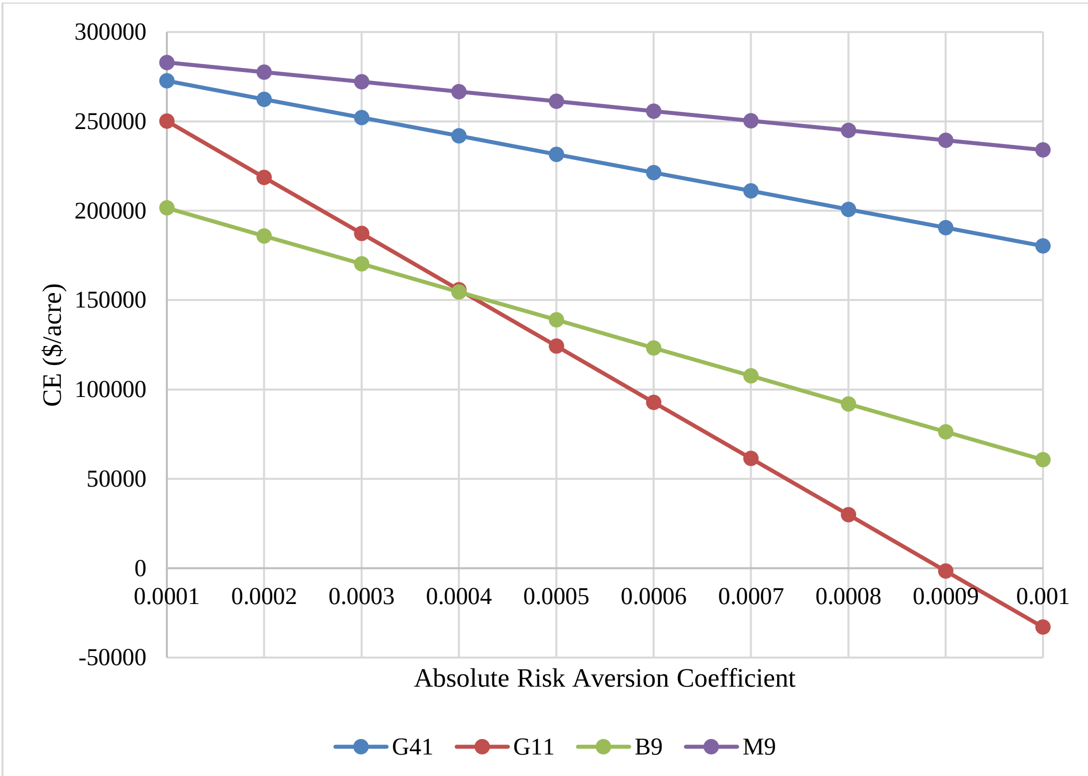

Figure 5-7 Certainty Equivalent under Different CARA for HC, TS System, VandeWalle Farm

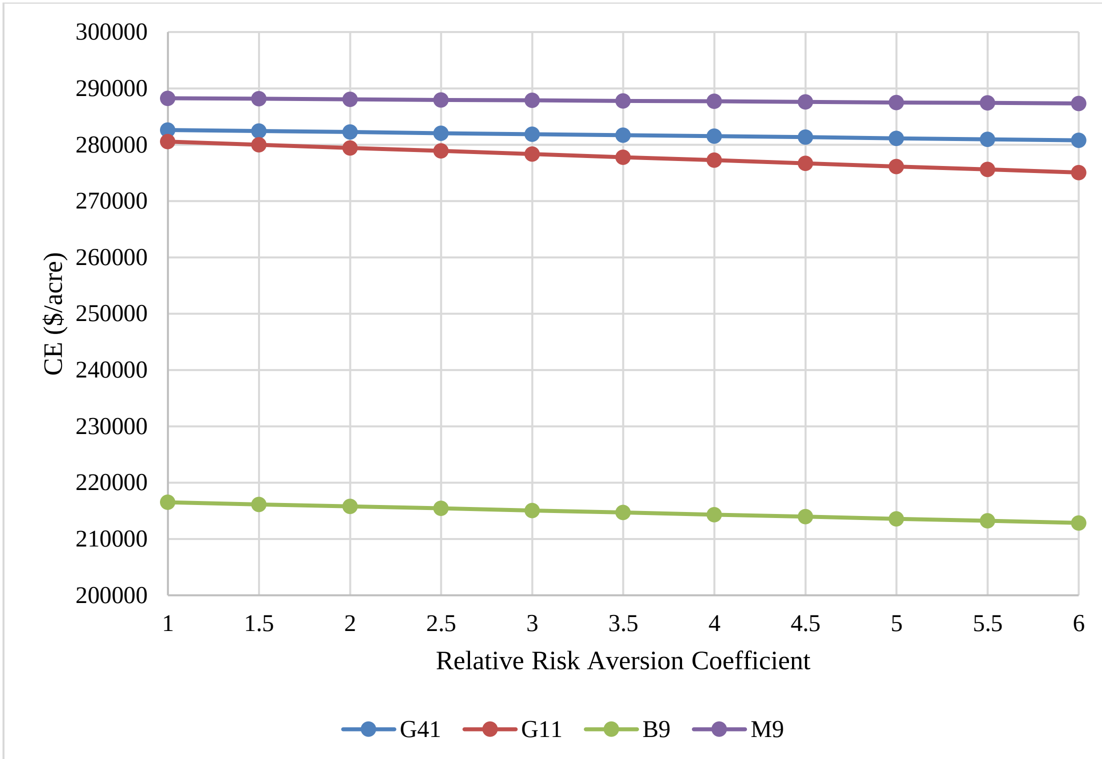

Figure 5-8 Certainty Equivalent under Different CRRA for HC, TS System, VandeWalle Farm

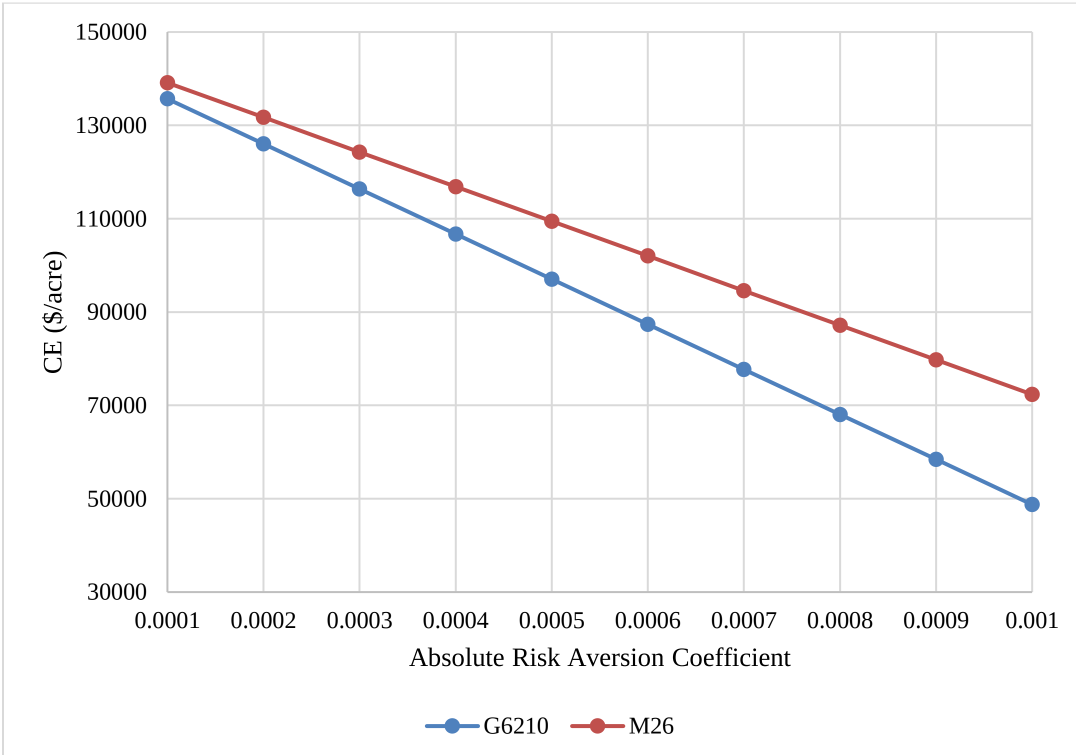

Figure 5-9 Certainty Equivalent under Different CARA for HC, SP System, VandeWalle Farm

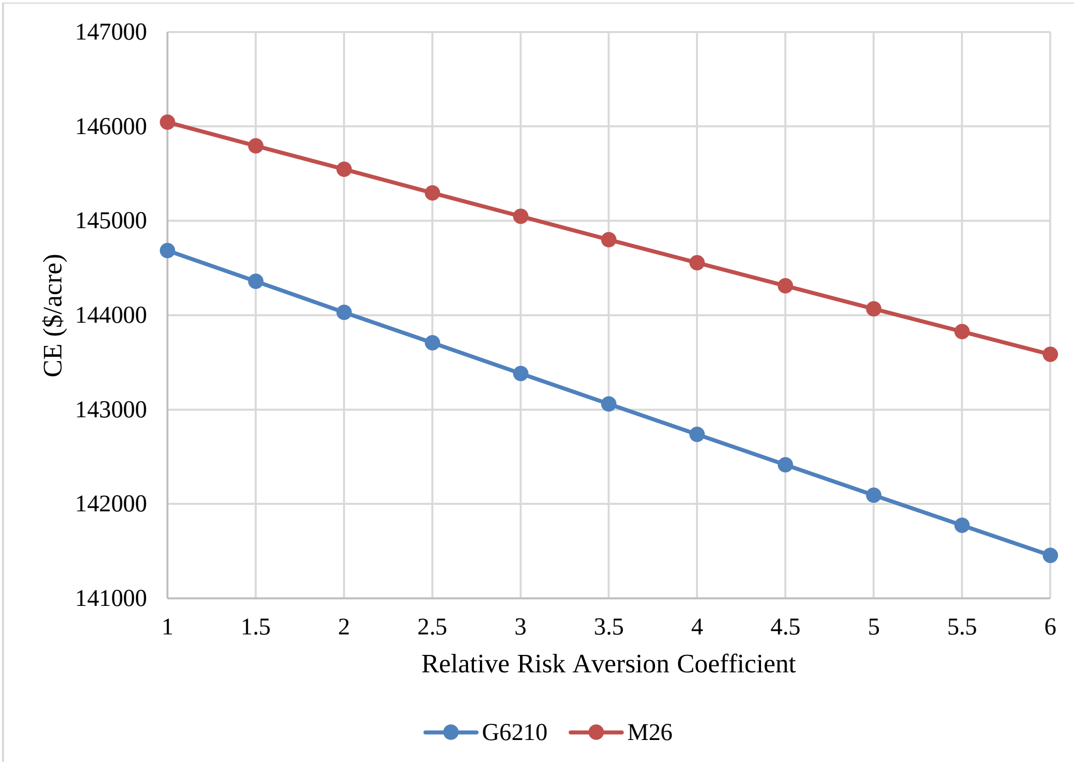

Figure 5-10 Certainty Equivalent under Different CRRA for HC, SP System, VandeWalle Farm

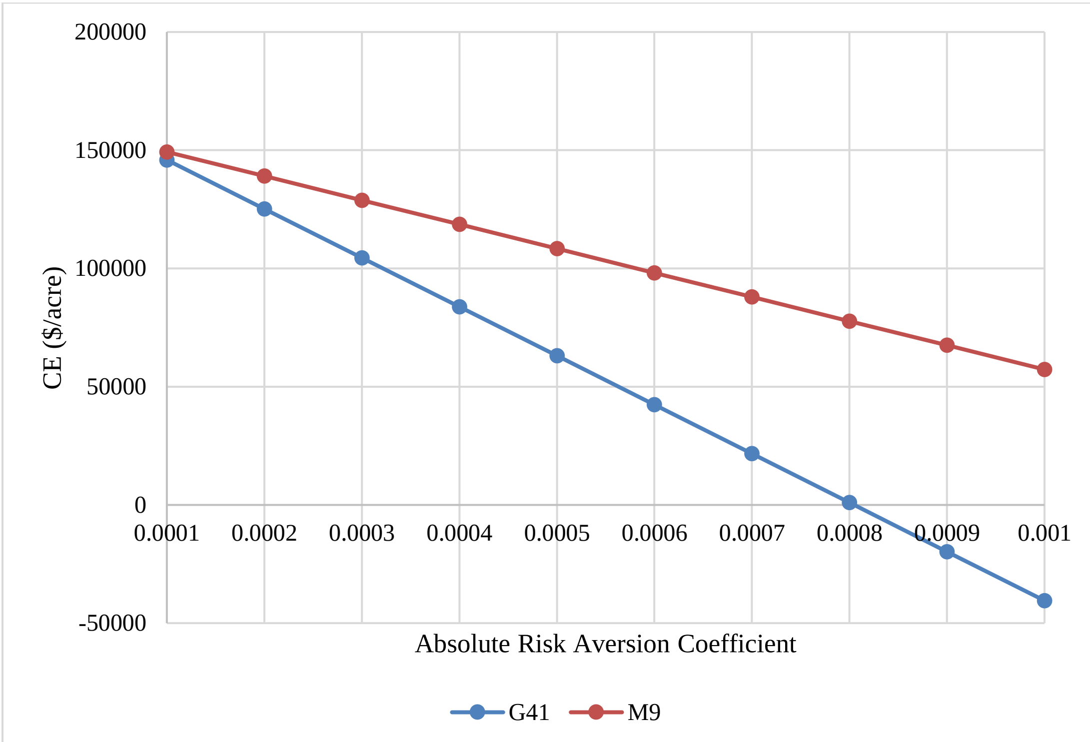

Figure 5-11 Certainty Equivalent under Different CARA for HC, VA System, VandeWalle Farm

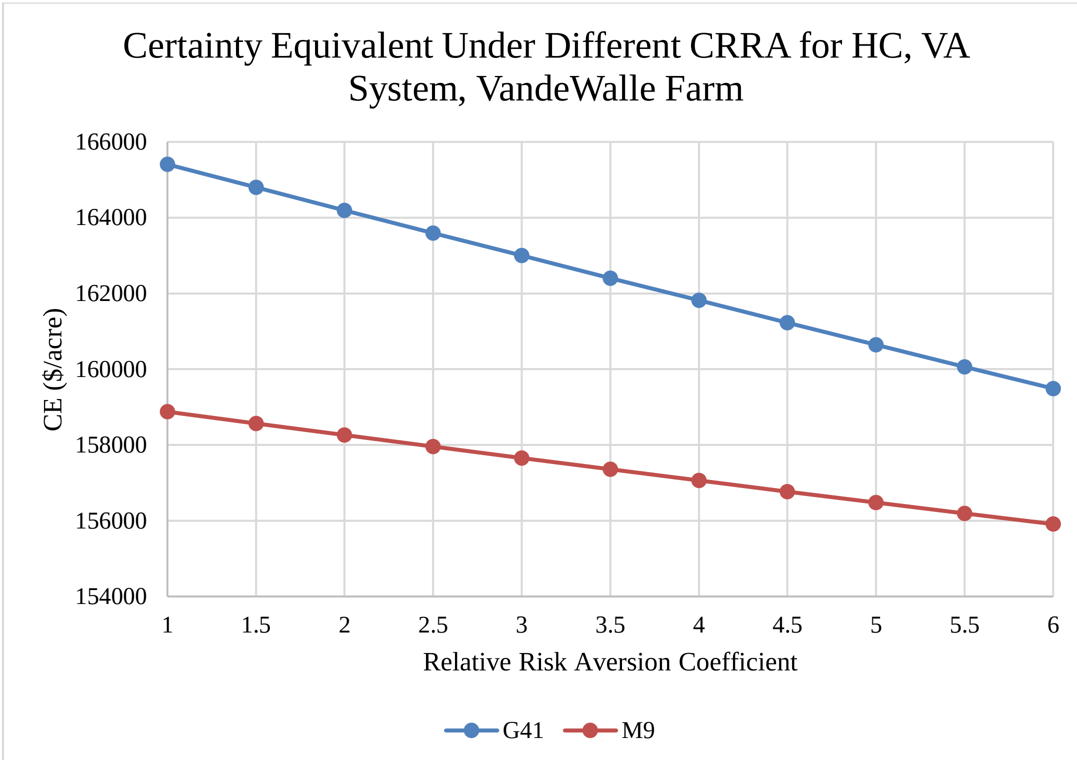

Figure 5-12 Certainty Equivalent under Different CRRA for HC, VA System, VandeWalle Farm

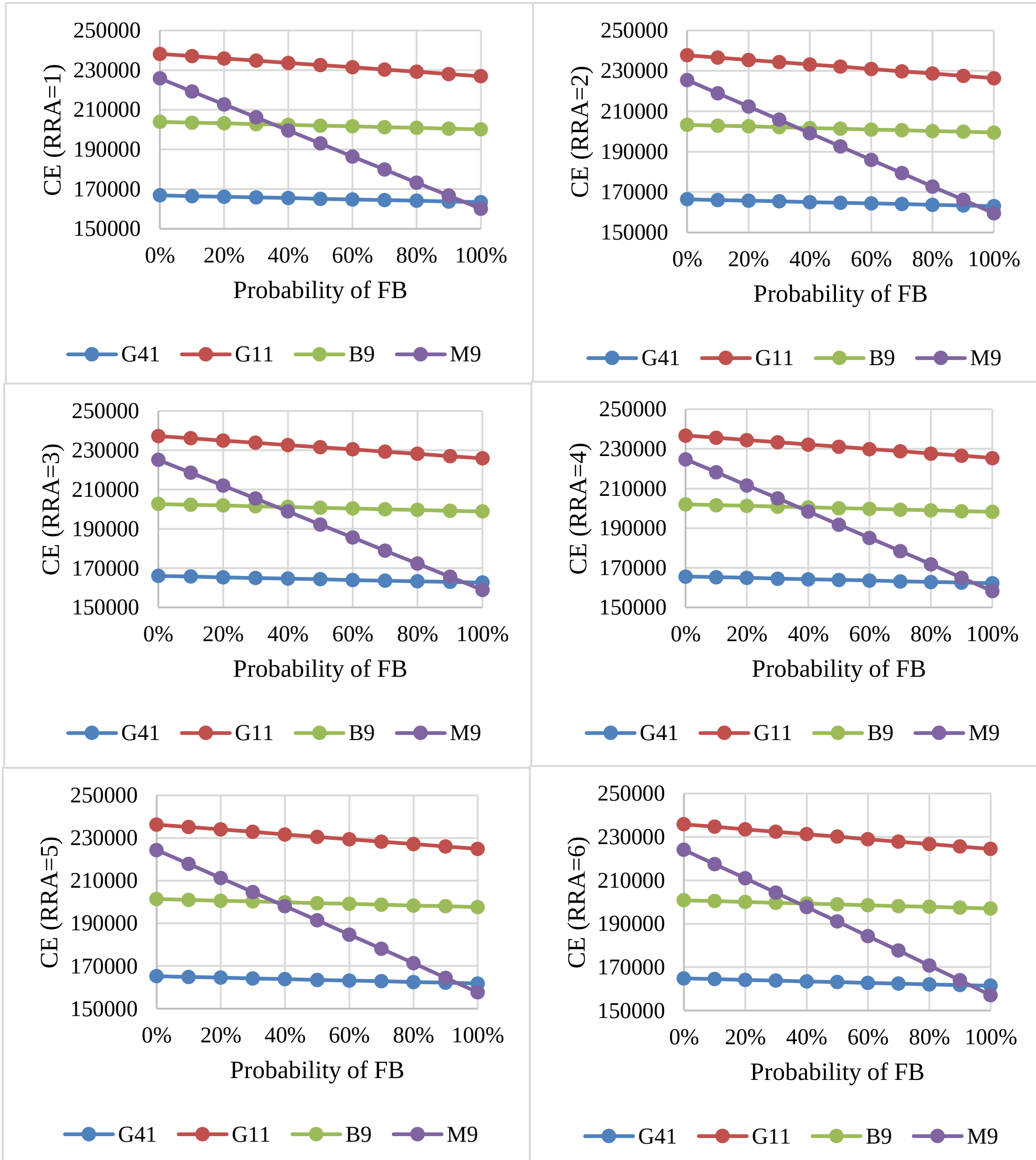

Figure 5-13 Certainty Equivalent under Different CRRA for HC, SA System, VandeWalle Farm for Different Probability of Fire Blight

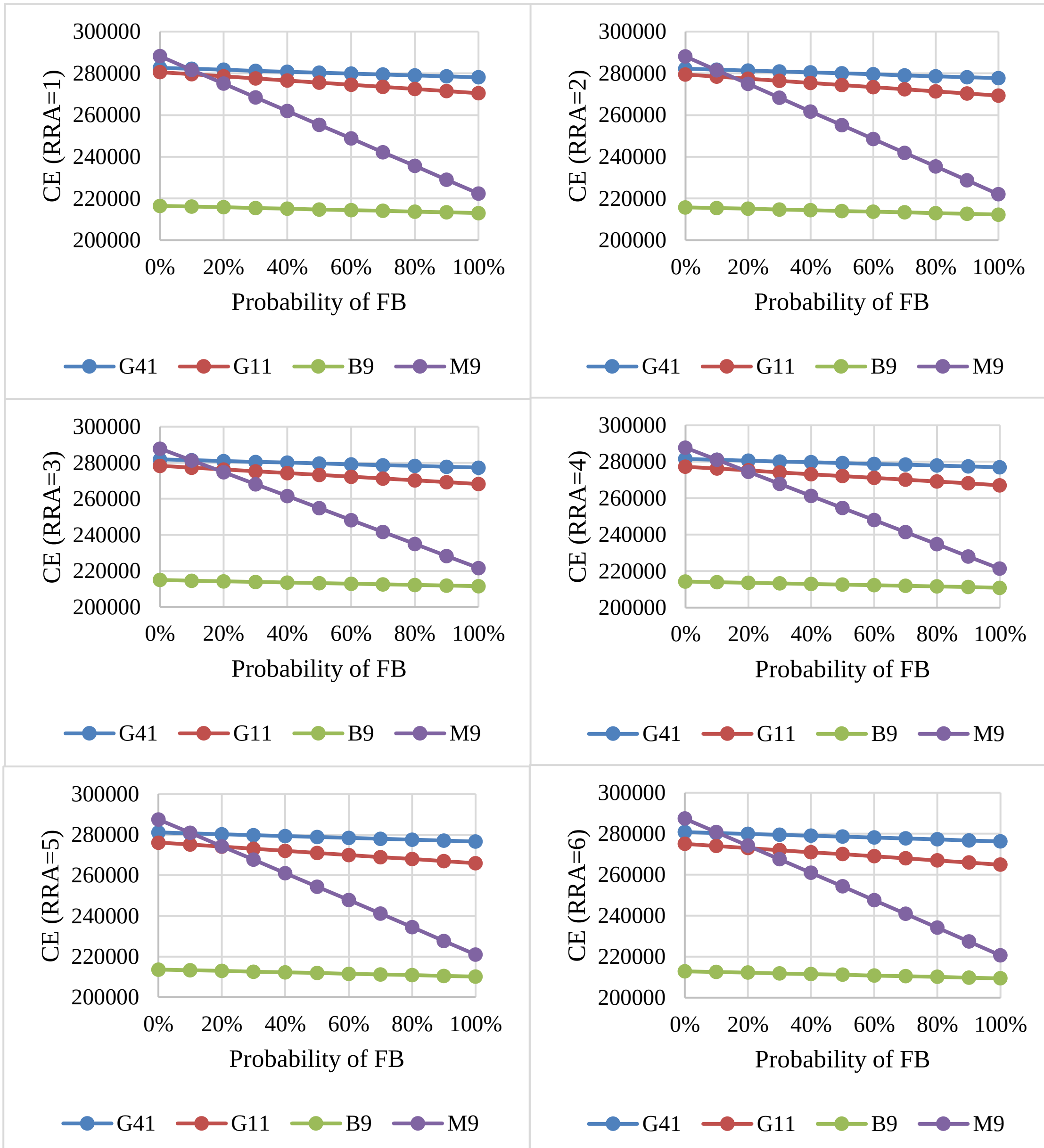

Figure 5-14 Certainty Equivalent under Different CRRA for HC, TS System, VandeWalle Farm for Different Probability of Fire Blight

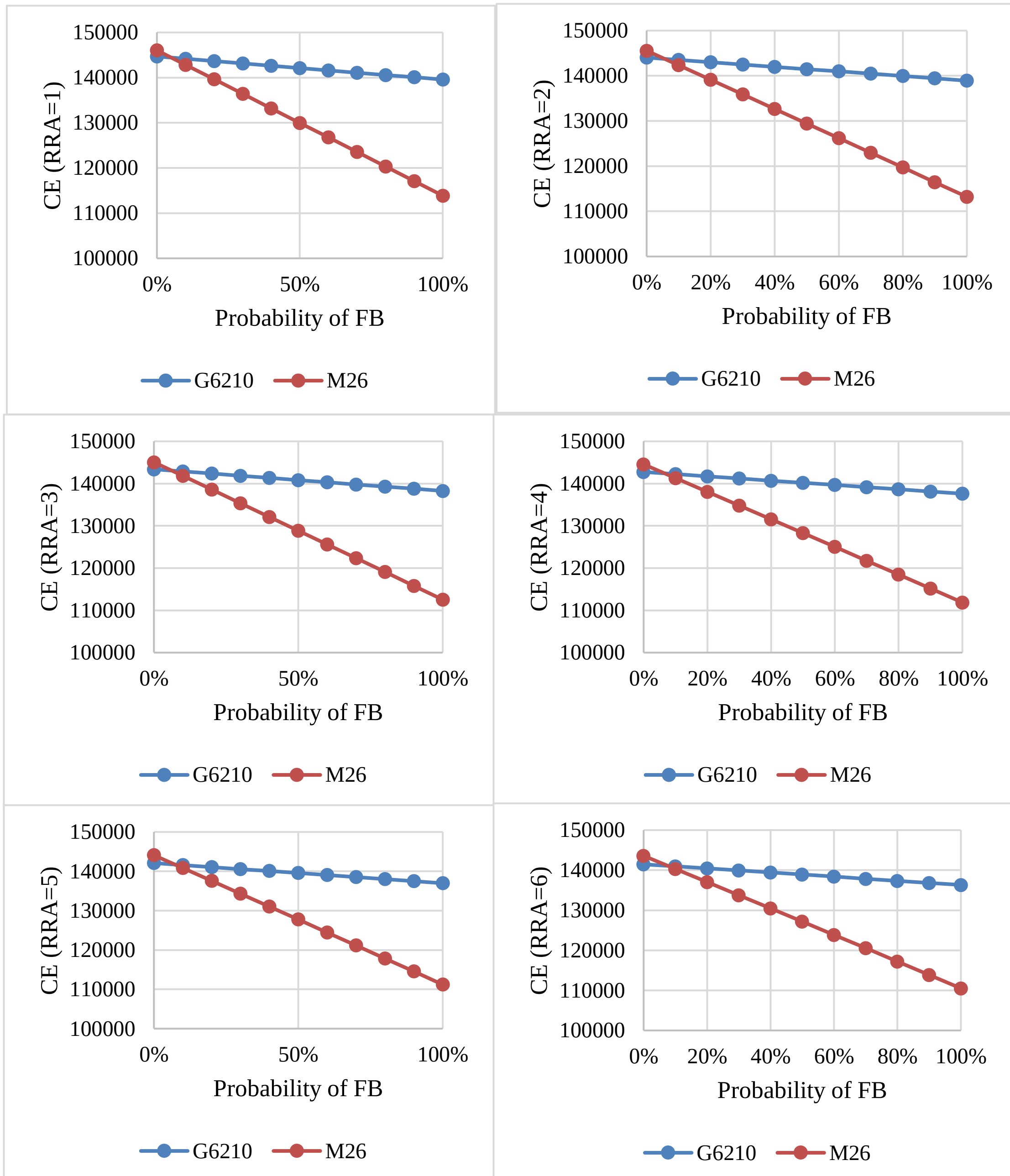

Figure 5-15 Certainty Equivalent under Different CRRA for HC, SP System, VandeWalle Farm for Different Probability of Fire Blight

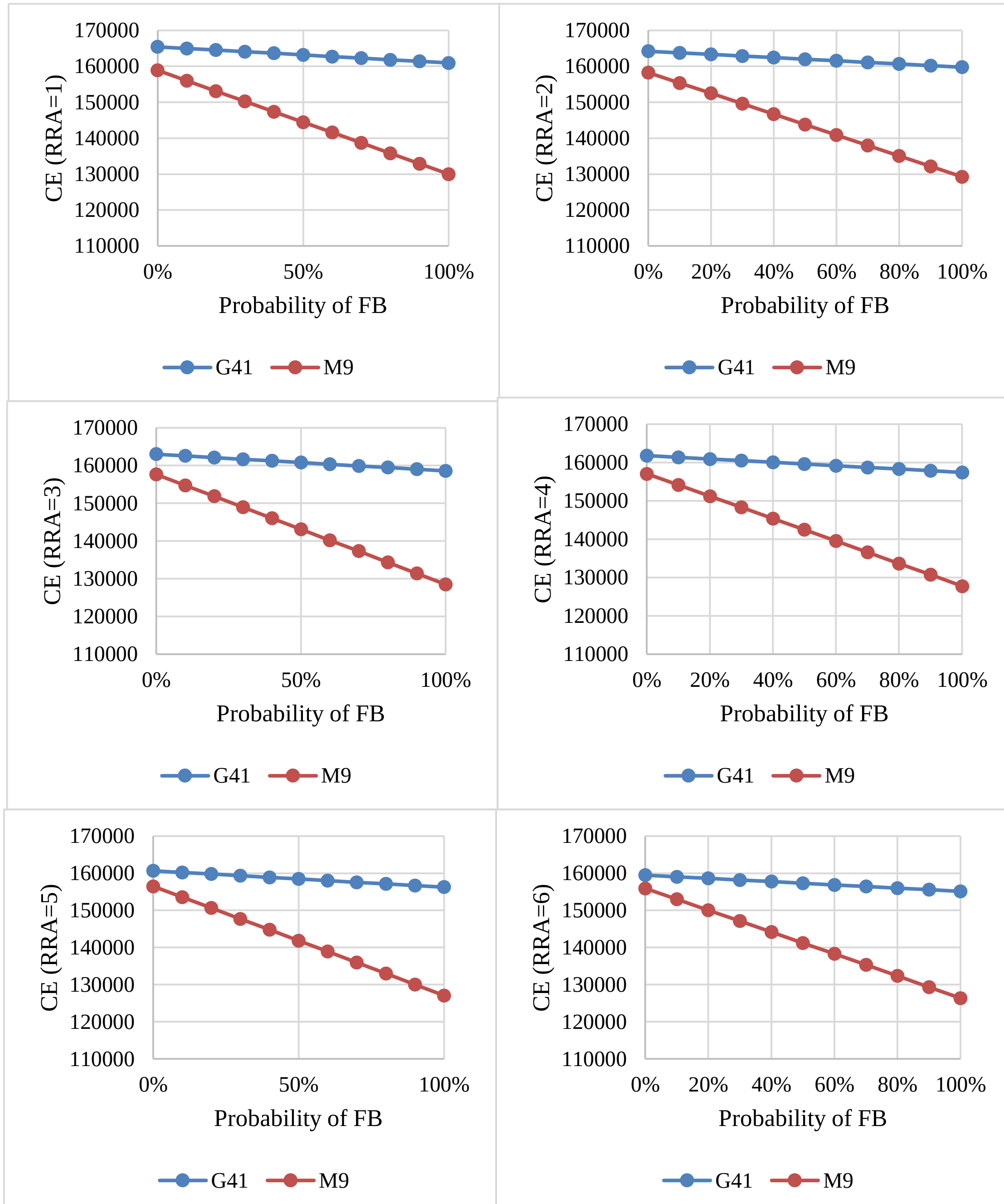

Figure 5-16 Certainty Equivalent under Different CRRA for HC, VA System, VandeWalle Farm for Different Probability of Fire Blight

Chapter 6 Conclusion and Discussion

6.1 Summary

6.1.1 Statistical Summary of Yields, Prices, Fruit Quality, and ANPV Results

The statistical summary of the yield, price, and quality data, plus results for the ANPV is shown in table 6-1 and table 6-2. As for the ANPV, In the high density systems (SA, TS), in 5 out of the 8 cases G11 generated the largest expected ANPV, mainly because G11 generated higher yields; in 4 out of the 8 cases B9 generated the smallest expected ANPV. In lower density systems (SP, VA), 5 out of the 8 cases G6210 and G41 generated larger expected ANPV than M26 and M9, mainly because G6210 and G41 generated higher yields.

In general, in 12 out of the 16 cases, the order of the expected ANPV was almost the same as the order of yield, and therefore we can conclude that yield plays an important role in determining the expected ANPV. In 13 out of the 16 cases, the order of price is almost the same as the order of quality, therefore we can conclude that quality plays an important role in determining the price, as B9 generates higher quality in 6 out of the 8 cases, and also generated higher price in 6 out of 8 cases.

6.1.2 Summary of the Sensitivity Analysis

As for the ANPV sensitivity analysis, in higher density systems (SA, TS), 6 out of the 8 cases the expected ANPV of M9 is the largest (or the second largest) compared with G11, G41, and B9. But, once the probability of fire blight increases, the expected ANPVs of G11, G41 and B9 exceed M9 in 5 out of the 8 cases, which indicates that

G11 and G41 are likely to be strong alternative technologies to M9. As for B9, it also resists fire blight, but it generates the lowest (or the second lowest) expected ANPV in 6 out of 8 cases because it is not as horticulturally strong as G11 and G41. As for the lower density systems (SP, VA), in 5 out of the 8 cases, the expected ANPVs of G6210 and G41 are larger than the expected ANPVs of M26 and M9. In other three cases, 2 out of the 3 have expected ANPV for G6210 that exceeds the expected ANPV of M26 as the probability of fire blight increases, which indicates G6210 and G41 are likely good alternative technologies for M26 and M9 in the lower density systems.

6.1.3 Summary of results from the Certainty Equivalents Analysis

Certainty equivalents for the baseline situations under CARA and CRRA show that as a farmer's risk aversion increases (indicated by the risk aversion coefficient,) the less likely they will choose the technology package with larger ANPV standard deviation. As for the constant absolute risk aversion (CARA) results, the changes are more dramatic as the risk aversion coefficients increase. Recall the certainty equivalent function, we can conclude that this function assigns a very large weight to the variance, which can mainly explain the dramatic change as the risk aversion coefficient increases. Compared with the results generated by the constant relative risk aversion (CRRA) model, the results of CARA are often the opposite. In 7 out of 16 cases, CARA results show the smallest negative slope, indicating the largest potential risk, and in even one case, it turns to be negative. But for CRRA results, because the general results are flatter, the certainty equivalents of the rootstocks that generate a lower certainty equivalent as absolute risk aversion increases are still larger than other rootstocks in the CRRA results. Therefore, the CARA results are likely to be exaggerated. Furthermore, based on a similar study by Röhrig (2018), results suggest that relative risk aversion coefficient be used instead of an absolute risk aversion coefficient because relative risk aversion is unit free and not affected by different levels of wealth. Also, absolute risk aversion is more often applied in a transitory income situation, which indicates that it does not fit well for an apple farm economic analysis as the rootstock investment is a long run commitment. So, we conclude that the CRRA results are more convincing. Based on the CRRA results, in high density systems, in 5 out of the 8 cases, G11 generates the largest certainty equivalents. In 3 out of 8 cases, M9 generated the largest certainty equivalent. In the low density systems, in 3 out of the 8 cases, G41 generated the highest certainty equivalents. For 2 out of the 8 cases, G6210 generated the highest certainty equivalent; 2 out of 8 cases, M26 generated the highest certainty equivalents; and in one case, M9 generated the highest certainty equivalent.

6.1.4 Summary of the Sensitivity Analysis of Fire Blight under CRRA

In the section that studied the sensitivity analysis under CRRA, all results present large decreasing slopes of M9 and M26, which indicate their vulnerability of fire blight. Also, when the RRA is 1, the certainty equivalent results are similar to the numerical results. There are 7 out of 16 cases where the certainty equivalents of G11, G41, and G6210 are always larger than the certainty equivalents of M9, B9, and M26. As the

RRA increases, in 8 out of 16 cases, a switch from M9 and M26 to G11, G6210, and G41 are preferred because of risk aversions and larger probability of fire blight.

6.2 Implications for Private Firms

In conclusion, all results indicated that G11, G41, and G6210 perform better than M9, M26, and B9 in generating higher yields, which is the main reason that Geneva rootstocks obtain higher accumulated net present values. If fire blight does not happen, the certainty equivalents of selected Geneva rootstocks are similar to the certainty equivalents of current rootstocks. However, once the probability of Fire Blight increases, it becomes more economically compelling to change from current rootstocks to Geneva rootstocks.

Furthermore, we subtract the certainty equivalents of Geneva rootstocks with the certainty equivalents of current rootstocks across location, variety, planting system and rootstocks, we can estimate the investment value of Geneva rootstocks. The formula we use is:

$$Investment\ value\ (Geneva\ Rt) = \overline{CE}(Geneva\ Rt) - \overline{CE}(Current\ Rt) \quad , \tag{6.1}$$

where the *Geneva Rt* represents Geneva apple rootstocks, (G11, G41 and G6210), and *Current Rt* represents current apple rootstocks, (M9, M26 and B9). The results are shown in table 6-3 that indicates the estimated investment value of Geneva rootstocks ranges from \$7.35 to \$42.52 per tree as the probability of fire blight increases.

6.3 Ideas for Future Research

The data used here were from an experimental field trial, and the situation may be different from a real operational farm. Future work could design a survey and distribute it to farmers who adopt both Geneva apple rootstocks and current apple rootstocks. The goal of such a survey would be to compare the quality, price and yield, and moreover, farmers' opinions about these rootstocks, such as the learning curve of Geneva rootstocks. In addition, researchers can evaluate more variables, such as skin color or soluble solids content to quantify fruit quality and collect a larger data to do a difference in difference analysis of the technology adoption. Future research might include at least five out of six major production regions of New York State and Washington State to make the result more representative.

TABLE

Table 6-1 Summary for ANPV, Yield, Price, Quality for Dressel farm

For Fuji, Dressels Farm:	For Gala, Dressels Farm:
ANPV: SA system: M9>G11>G41>B9	ANPV: SA system: G11>B9>G41>M9
Yield: SA system: M9>G11>G41>B9	Yield: SA system: G11>G41>M9>B9
Price: SA system: B9>M9>G11>G41	Price: SA system: B9>M9>G11>G41
Quality(XXFancy): SA system: B9>M9>G41>G11	Quality(XXFancy): SA system: B9>G11>G41=M9
ANPV: TS system: G11>M9>B9>G41	ANPV: TS system: G11>G41>M9>B9
Yield: TS system: G11>M9>G41>B9	Yield: TS system: G41>G11>M9>B9
Price: TS system: B9>M9>G11>G41	Price: TS system: B9>G41>G11>M9
Quality(XXFancy): TS system: B9>G41>M9>G11	Quality(XXFancy): TS system: B9>M9>G41>G11
ANPV: SP system: G6210>M26	ANPV: SP system: G6210>M26
Yield: SP system: G6210>M26	Yield: SP system: G6210>M26
Price: SP system: G6210>M26	Price: SP system: G6210>M26
Quality(XXFancy): SP system: M26>G6210	Quality(XXFancy): SP system: G6210>M26
ANPV: VA system: G41>M9	ANPV: VA system: M9>G41
Yield: VA system: G41>M9	Yield: VA system: M9>G41
Price: VA system: M9>G41	Price: VA system: M9>G41
Quality(XXFancy): VA system: M9>G41	Quality(XXFancy): VA system: M9>G41

Table 6-2 Summary for ANPV, Yield, Price, Quality for VandeWalle farm

For Gala, VandeWalle Farm:	For HC, VandeWalle Farm:
ANPV: SA system: G41>M9>G11>B9	ANPV: SA system: G11>M9>B9>G41
Yield: SA system: M9>G41>G11>B9	Yield: SA system: M9>G41>G11>B9
Price: SA system: G41>M9>B9>G11	Price: SA system: B9>G11>M9>G41
Quality(XXFancy): SA system: G41>M9>B9>G11	Quality(XXFancy): SA system: G11=B9>G41>M9
ANPV: TS system: G11>B9>M9>G41	ANPV: TS system: M9>G41>G11>B9
Yield: TS system: G41>G11>M9>B9	Yield: TS system: M9>G11>G41>B9
Price: TS system: B9>G11>M9>G41	Price: TS system: G41>M9>G11>B9
Quality(XXFancy): TS system: B9>G11>M9>G41	Quality(XXFancy): TS system: G41>G11>B9>M9
ANPV: SP system: M26>G6210	ANPV: SP system: M26>G6210
Yield: SP system: M26>G6210	Yield: SP system: M26>G6210
Price: SP system: M26>G6210	Price: SP system: M26>G6210
Quality(XXFancy): SP system: G6210>M26	Quality(XXFancy): SP system: M26>G6210
ANPV: VA system: G41>M9	ANPV: VA system: G41>M9
Yield: VA system: M9>G41	Yield: VA system: M9>G41
Price: VA system: G41>M9	Price: VA system: G41>M9
Quality(XXFancy): VA system: M9>G41	Quality(XXFancy): VA system: G41>M9

Table 6-3 Investment Value of Geneva apple rootstocks under CRRA

	Investment Value Across Probability of Fire Blight ($/tree)										
CRRA	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1	7.68	10.00	12.32	14.64	16.97	19.31	21.66	24.02	27.71	32.40	34.33
2	7.60	9.94	12.29	14.64	17.01	19.40	21.81	24.31	27.23	29.17	31.84
3	7.53	9.89	12.27	14.66	17.08	19.53	22.07	24.98	28.78	31.35	33.14
4	7.46	9.85	12.26	14.70	17.18	19.75	22.48	25.75	29.44	32.07	42.52
5	7.40	9.82	12.27	14.77	17.34	20.03	22.95	26.31	29.70	32.26	34.26
6	7.35	9.81	12.31	14.87	17.53	20.33	23.35	26.64	29.86	32.47	35.56

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Appendix

Appendix I: Fuji, Gala Sensitivity Analysis of Fire Blight

For Dressels Farm, Fuji variety, in the SA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-1. The changing tendencies of expected ANPV for G41, G11, B9, M9 in different probabilities of fire blight ranges from 0% to 100% with incremental change of 10%. The larger slope rate of M9 indicates it does not resist to fire blight, the expected ANPV significantly decreases as fire blight becomes severe, while for G41, G11, and B9, tendencies are flatter as increasing probability of fire blight. Moreover, when probability of fire blight is larger than 20%, the expected ANPV of M9 will be smaller than expected ANPV of G11. When probability of fire blight is larger than around 55%, the expected ANPV of M9 will be smaller than expected ANPVs of G41 and B9. For B9, its expected ANPV is always smaller than G11, and very close to G41.

For the same farm, same variety, in the TS system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-2. This graph shows the decreasing tendency of ANPV for the increasing probability of fire blight. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight, which is the same as in the SA system. The slope rates for G41, G11 and B9 are flatter because of their resistance of fire blight. For Fuji, growing in TS planting system, the ANPV of G11 is always larger than the ANPV of M9. When the probability of fire blight is larger than around 75%, the ANPV of B9 is larger than the

ANPV of M9. When the probability of fire blight is larger than 80%, the ANPV of G41 is larger than the ANPV of M9.

For the same farm, in the same variety, in the SP system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-3. This graph shows the decreasing tendency of ANPV for the increasing probability of fire blight. The larger decreasing slope of M26 indicates its susceptibility to fire blight. The ANPV of G6210 is always larger than the ANPV of M26; Also, in the VA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-4. This graph shows the decreasing tendency of ANPV for the increasing probability of fire blight. The larger decreasing slope of M9 indicates its susceptibility to fire blight. The ANPV of G41 is always larger than the ANPV of M9.

As For the Gala variety, in the Dressels Farm, in the SA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-5. This graph shows for Gala, growing in the SA system in the Dressels Farm, the expected ANPV of M9 is always less than G41, G11, B9, and is very vulnerable to fire blight indicated by larger decreasing slope rate. In the TS system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-6. This graph shows for Gala, growing in TS system, G41 and G11 are always better than M9 and B9. And once the probability of fire blight is more than around 55%, the expected ANPV of B9 is larger than the expected ANPV of M9. In the SP system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-7. This graph shows for Gala, growing in SP system, the expected ANPV of G6210 is always larger than the expected ANPV of M26 for all probabilities of fire blight. And the larger decreasing slope of M26 indicates its vulnerability of fire blight. In the VA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-8. This graph shows for Gala variety, growing in the VA system, although fire blight affects expected ANPV of M9 a lot, M9 still generates the higher expected ANPV than G41 when the probability of fire blight is 100%. So, for Gala in VA system, G41 may not be a good choice in terms of expected ANPV.

As for the Gala variety, in the VandeWalle Farm, in the SA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-9. This graph shows the expected ANPV of G41 is always higher than expected ANPV of M9, G11, and B9. Although, the decreasing slope rate of M9 indicates lower expected ANPV as higher the probability of fire blight, the expected ANPV of M9 is still larger than the expected ANPV of G11 and B9, even the fire blight is 100% occurred, which points out that G11 and B9 may not be choices for Gala in the SA system for VandeWalle Farm. In the TS system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-10. This graph shows the expected ANPVs of G11 and B9 are always higher than expected ANPVs of M9 and G41. As for G11 and B9, because B9 has lower infected proportion of fire blight (3%-5%) than G11 (12%), so, when the probability of fire blight is larger than 50%, the expected ANPV of B9 exceeds the expected ANPV of G11. As for M9 and G41, the decreasing slope rate of M9 indicates its vulnerability of fire blight, the expected ANPV of M9 is lower than the expected ANPV of G41 if the probability of fire blight is larger than 10%.

For the same variety, same farm location, in the SP system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-11. This graph show the expected ANPV of M26 is larger than the expected ANPV of G6210 when the probability of fire blight is 0. However, because the susceptibility of M26 to fire blight indicated by the larger decreasing slope rate, once the probability of fire blight is larger than around 30%, the expected ANPV of G6210 exceeds the expected ANPV of M26. In the VA system, the sensitivity analysis for expected ANPV ($/acre) in different probabilities of fire blight is shown in Figure 8-12. This graph show the expected ANPV of G41 is always larger than the expected ANPV of M9. The susceptibility of M9 to fire blight is indicated by the larger decreasing slope rate.

Appendix II: Fuji, Gala Certainty Equivalents under CARA and CRRA

In the Dressel Farm, for Fuji, SA planting system (908 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-13. Based on numerical expected ANPV results generated before, the comparisons of expected ANPV is M9>G11>G41>B9. However, the sequence is not the same in terms of certainty equivalent (CE). From 0.0001 to 0.0003, the sequence of CE is

M9>G11>B9>G41. The reverse sequence between B9 and G41 is due to B9 has smaller standard deviation, therefore risk-averse farmers are willing to choose B9 than G41 when their risk aversion coefficient is from 0.0001 to 0.0003. If farmers' absolute risk aversion coefficients (ARA) range from 0.0004 to 0.0008, the sequence of CE is G11>M9>B9>G41, which indicates farmers in this range are more willing to choose G11 than M9 because of larger standard deviation of M9 than G11. Then when ARA ranges from 0.0008 to 0.001, the sequence of CE is G11>B9>M9>G41, which indicates farmers are more willing to choose B9 than M9 because of B9's smaller standard deviation. Furthermore, when ARA equals to 0.001, the CE of G41 turns into negative number, which indicates farmers will not invest in this technology package when their ARA obtains 0.001.

In the same planting system, same rootstocks, certainty equivalents for relative risk aversions from 1 to 6 are compared on Figure 8-14. For relative risk aversions (RRA), the sequence of CE is M9>G11>B9>G41 from RRA 1 to RRA 6, which is the same sequence as the sequence of ARA from 0.0001 to 0.0003, but the sequence of RRA does not change from 1 to 6, which indicates CRRA utility function is less sensitive to change than CARA utility function when increasing relative risk aversion coefficients. The resulting sequence is also different from the numerical resulting sequence (M9>G11>G41>B9) generated from the simulation at the beginning.

In the Dressel Farm, for Fuji, TS planting system (1320 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-15.

The results exhibit the sequence of CE is G11>M9>B9>G41 from 0.0001 to 0.001, which is the same as the numerical result we generated before.

In the same planting system, same rootstocks, certainty equivalents for relative risk aversions from 1 to 6 are compared on Figure 8-16. The results exhibit the sequence of CE is G11>M9>B9>G41 from 1 to 6, which is the same as the numerical result and the CARA results we generated before.

In the Dressel Farm, for Fuji, SP planting system (340 trees/acre), two rootstocks, G6210, M26 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-17. The results exhibit the sequence of CE is G6210>M26 from 0.0001 to 0.001, which is the same as the numerical result we generated before. Moreover, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-18. The results exhibits the sequence of CE is G6210>M26 from 1 to 6, which is the same as the numerical result and the CARA results we generated before.

In the Dressel Farm, for Fuji, VA planting system (519 trees/acre), two rootstocks, G41, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-19. The results exhibit the sequence of CE is G41>M9 from 0.0001 to 0.0008, which is the same as the numerical result we generated before. But from 0.0009 to 0.001, G41<M9, which is due to standard deviation of G41 is larger than standard deviation of M9. Moreover, the comparisons of certainty equivalents for relative risk aversions from 1 to

6 are shown on Figure 8-20. The results exhibit the sequence of CE is G41>M9 from 1 to 6, which is the same as the numerical result we generated before.

As for Gala, in the same farm, SA planting system (908 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-21. The results show, for Gala, growing in SA system, in the Dressels farm, from 0.0001 to 0.0003 absolute risk aversion coefficient, the order of CE is G11>B9>G41>M9, which is the same as the numerical ANPV result. But at around 0.0003, the order of CE changes to B9>G11>G41>M9, which is due to the larger standard deviation of G11. And then, from around 0.00031 to 0.0005, the order of CE changes to B9>G41>G11>M9, which is also due to the larger standard deviation of G11. From 0.0005 to 0.001, the order of CE changes to G41>B9>M9>G11, which is almost different from the order at the beginning. Furthermore, from 0.0009 to 0.001, G11 even changes into negative number, which means farmers may not willing to invest it because of G11's larger standard deviation. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-22. The results show, for Gala, growing in SA system, in the Dressels farm, from 1 to 6 relative risk aversion, the order of CE is G11>B9>G41>M9, which is the same as the numerical ANPV result and the same as the results of ARA from 0.0001 to 0.0003.

In the TS planting system (1320 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-23. The results show for Gala, growing in TS system, under ARA, the order of CE is G11>G41>M9>B9 from 0.0001 to 0.0002, which is the same as the numerical result of expected ANPV. From 0.0003 to around 0.00085, the order of CE is G41>G11>M9>B9, which is due to the smaller standard deviation of G41 compared with G11. From 0.00085 to 0.0009, G41>M9>G11>B9, which is due to the larger standard deviation of G11. From 0.0009 to 0.001, the order changes to M9>G41>G11>B9, which is due to the larger standard deviations of G41. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-24. The results show for Gala, growing in TS system, under RRA, the order of CE is G11>G41>M9>B9 from 1 to 6, which is the same as the numerical result of expected ANPV and the same as the ARA results from 0.0001 to 0.0002.

In the SP planting system (340 trees/acre), two rootstocks, G6210, M26 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-25. The results exhibit the sequence of CE is G6210>M26 from 0.0001 to 0.001, which is the same as the numerical result we generated before. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-26. The results exhibit the sequence of CE is G6210>M26 from 1 to 6, which is the same as the numerical result and the CARA results we generated before.

In the VA planting system (519 trees/acre), two rootstocks, G41, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-27. The results exhibit the sequence of CE is M9>G41 from 0.0001 to 0.001, which is the same as the numerical expected ANPV result. Moreover, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-28. The results exhibit the sequence of CE is M9>G41 from 1 to 6, which is the same as the numerical result and CARA result.

In the VandeWalle Farm, for Gala, SA planting system (908 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-29. From 0.0001 to 0.0003, the order of CE is M9>G41>G11>B9, which is different from the numerical result generated before (G41>M9>G11>B9) because of larger standard deviation of G41 than M9. From 0.0003 to 0.001, the order of CE is M9>G41>B9>G11, which is due to the larger standard deviation of G11 than B9. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-30. The results show, for Gala, growing in SA system, in the Dressels farm, from 1 to 6 relative risk aversion, the order of CE is G41>M9>G11>B9, which is the same as the numerical ANPV result and the same as the results of ARA from 0.0001 to 0.0003.

In the TS planting system (1320 trees/acre), four rootstocks, G41, G11, B9, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-31. From 0.0001 to 0.001, the order of CE is G11>B9>M9>G41, which is the same as the numerical value generated before. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-32. The results show, for Gala, growing in SA system, in the Dressels farm, from 1 to 6 relative risk aversion, the order of CE is G11>B9>M9>G41, which is the same as the numerical ANPV result and the same as the results of ARA.

In the SP planting system (340 trees/acre), two rootstocks, G6210, M26 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-33. From 0.0001 to around 0.0004, the certainty equivalent of M26 is larger than the certainty equivalent of G6210, which is the same as the numerical value generated before. But from 0.0004 to 0.001, G6210 exceeds M26 because of larger standard deviation of M26. And the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-34. The results show, from 1 to 6 relative risk aversion, the order of CE is M26>G6210, which is the same as the numerical ANPV result and the same as the results of ARA from 0.0001 to around 0.0004.

In the VA planting system (519 trees/acre), two rootstocks, G41, M9 are compared in certainty equivalents. The comparisons of certainty equivalents for absolute risk aversions from 0.0001 to 0.001 are shown on Figure 8-35. From 0.0001 to around 0.001, the certainty equivalent of G41 is larger than the certainty equivalent of M9, which is the same as the numerical value generated before. Also, the comparisons of certainty equivalents for relative risk aversions from 1 to 6 are shown on Figure 8-36. From 1 to 6, the certainty equivalent of G41 is larger than the certainty equivalent of M9, which is the same as the numerical value generated before and the value of ARA.

Appendix III: Fuji, Gala Sensitivity Analysis of Fire Blight under CRRA

For Fuji growing in the SA system, in the Dressel Farm, Figure 8-37 shows tendencies of certainty equivalents of G41, G11, B9, M9 from RRA 1 to 6 under different probabilities of fire blight. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results, as RRA increases, the fire blight probability of the cross point between M9 and G11 decreases, the fire blight probability of the cross point between M9 and B9 decreases, and the fire blight probability of the cross point between M9 and G41 increases. These indicate that as a farmer becomes more risk averse, he is more willing to change from M9 to G11, from M9 to B9 because of smaller variances of G11 and B9; and less willing to change from M9 to G41 because of larger variance of G41. Therefore, when the probability of fire blight ranges from 15% to 20%, farmers want to change from M9 to G11; when the probability of fire blight ranges from 50% to 55%, farmers want to change from M9 to B9; when the probability of fire blight ranges from 60% to 70%, farmers want to change from M9 to G41.

In the TS system, Figure 8-38 shows tendencies of certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of G11 is always larger than the certainty equivalents of M9, G41 and B9. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results, as RRA increases, the fire blight probability of the cross point between M9 and B9 decreases, and the fire blight probability of the cross point between

M9 and G41 decreases. These indicates as farmer becomes more risk averse, he is more willing to change from M9 to B9, from M9 to G41 because of smaller variances of B9 and G41. Therefore, when the probability of fire blight ranges from 63% to 70%, farmers want to change from M9 to B9; when the probability of fire blight ranges from 70% to 75%, farmers want to change from M9 to G41.

In the SP system, Figure 8-39 shows tendencies of certainty equivalents of G6210, M26 under different probabilities of fire blight from RRA 1 to 6. In this case, we omitted the probability of fire blight in 90% and 100% because these results have negative ANPVs that are unable to work in CRRA utility function. Moreover, the exclusions do not affect overall results. The certainty equivalent of G6210 is always larger than the certainty equivalent of M26. The larger decreasing slope rate of M26 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As probability of fire blight increases, the certainty equivalent of M26 decreases at an increasing rate. As RRA increases, the tendency of increasing reduced rate becomes stronger when RRA equals 4, and flatter when RRA equals 6.

In the VA system, Figure 8-40 shows tendencies of certainty equivalents of G41, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of G41 is always larger than the certainty equivalent of M9. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As probability of fire blight increases, the certainty equivalent of M9 decreases at an increasing rate. As RRA increases, the tendency of increasing reduced rate becomes stronger.

As For the Gala growing in the SA system, in the Dressel Farm, Figure 8-41 shows tendencies of certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight from RRA 1 to 6. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. In this case, we omitted the probability of fire blight in 90% and 100% because these results have negative ANPVs that are unable to work in CRRA utility function. Moreover, the exclusions do not affect overall results. As the RRA increases, the sequence order of certainty equivalents are always G11>B9>G41>M9 in different probabilities of fire blight. As probability of fire blight increases, the certainty equivalent of M9 decreases at an increasing rate. As RRA increases, the tendency of increasing reduced rate becomes stronger.

In the TS system, Figure 8-42 shows tendencies of certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalents of G11 and G41 are always larger than the certainty equivalents of M9 and B9. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results, as RRA increases, the fire blight probability of the cross point between G11 and G41 decreases, and the fire blight probability of the cross point between M9 and B9 does not change. These indicates as farmer becomes more risk averse, he is more willing to change from G11 to G41 because of smaller variances of G41. Therefore, when the probability of fire blight ranges from 10% to 20%, farmers want to change from G11 to G41; when the probability of fire blight is around 50%, farmers want to change from M9 to B9.

In the SP system, Figure 8-43 shows tendencies of certainty equivalents of G6210, M26 under different probabilities of fire blight from RRA 1 to 6. In this case, we omitted the probability of fire blight in 80%, 90% and 100% because these results have negative ANPVs that are unable to work in CRRA utility function. Moreover, the exclusions do not affect overall results. The certainty equivalent of G6210 is always larger than the certainty equivalent of M26. The larger decreasing slope rate of M26 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As probability of fire blight increases, the certainty equivalent of M26 decreases at an increasing rate. As RRA increases, the tendency of increasing reduced rate becomes stronger.

In the VA system, Figure 8-44 shows tendencies of certainty equivalents of G41, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of M9 is always larger than the certainty equivalent of G41 when RRA ranges from 1 to 4. When RRA equals 5, farmers want to change from M9 to G41 when the probability of fire blight is larger than 99%. When RRA equals 6, farmers want to change from M9 to G41 when the probability of fire blight is larger than 95%. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As probability of fire blight increases, the certainty equivalent of M9 decreases at an increasing rate. As RRA increases, the tendency of increasing reduced rate becomes stronger.

As for Gala growing in the SA system, in the VandeWalle Farm, Figure 8-45 shows tendencies of certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight from RRA 1 to 6. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. As the RRA increases, the sequence order of certainty equivalents are always G41>M9>G11>B9 in different probabilities of fire blight.

In the TS system, Figure 8-46 shows tendencies of certainty equivalents of G41, G11, B9, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalents of G11 and B9 are always larger than the certainty equivalents of G41 and M9. The larger decreasing slope rate of M9 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results, as RRA increases, the fire blight probability of the cross point of G11 and B9 increases, and the fire blight probability of the cross point of G41 and M9 almost does not change because of their similar variances. These indicates as farmer becomes more risk averse, he is less willing to change from G11 to B9 because of smaller variances of G11. Therefore, when the probability of fire blight ranges from 50% to 90%, farmers want to change from G11 to B9; when the probability of fire blight is around 10%, farmers want to change from M9 to G41.

In the SP system, Figure 8-47 shows tendencies of certainty equivalents of G6210, M26 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of M26 is larger than the certainty equivalent of G6210 at the beginning, as the probability of fire blight increases, the certainty equivalent of M26 becomes smaller than the certainty equivalent of G6210. The larger decreasing slope rate of M26 indicates its vulnerability of fire blight. It also shows when RRA equals to 1, the certainty equivalent results are similar to the numerical results. As RRA increases, the fire blight probability of the cross point of G6210 and M26 decreases. These indicates as farmer becomes more risk averse, he is more willing to change from M26 to G6210 because of smaller variances of G6210. The fire blight probability to change from M26 to G6210 ranges from 22% to 30%. In another lower density system, the VA system, Figure 8-48 shows tendencies of certainty equivalents of G41, M9 under different probabilities of fire blight from RRA 1 to 6. The certainty equivalent of G41 is always larger than the certainty equivalent of M9.

Appendix IV: FIGURE

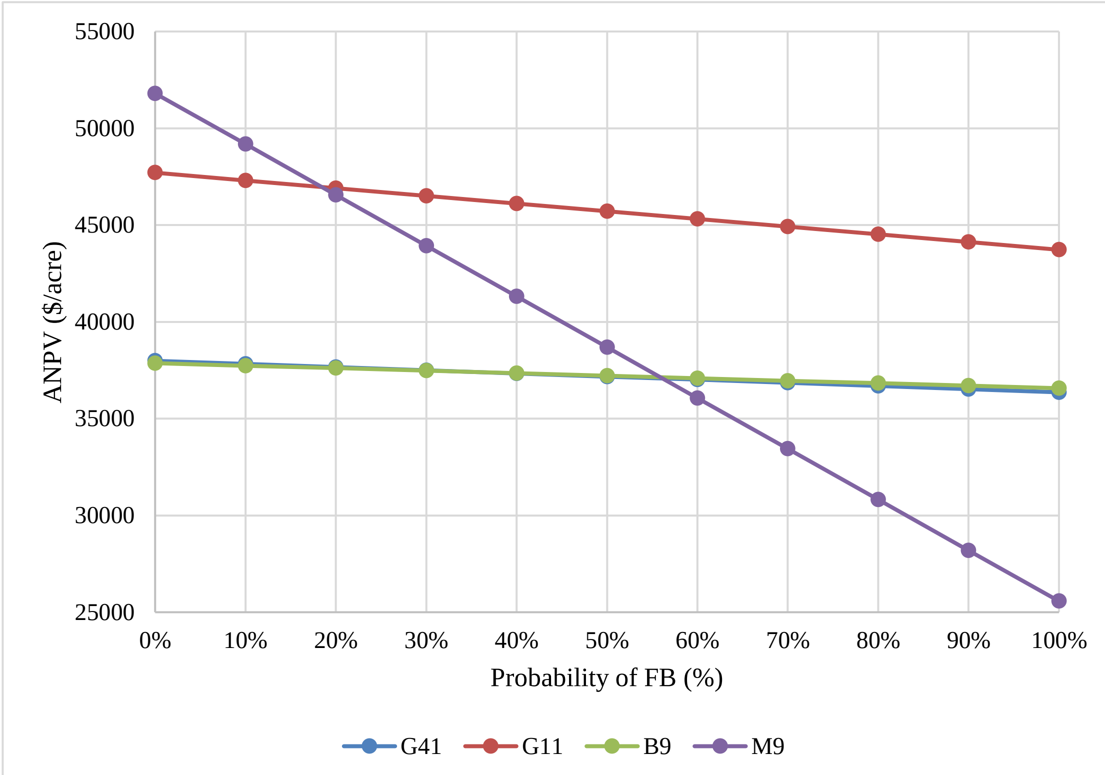

Figure 8-1 ANPV for Fuji, SA for Different Probabilities of Fire Blight, Dressel Farm

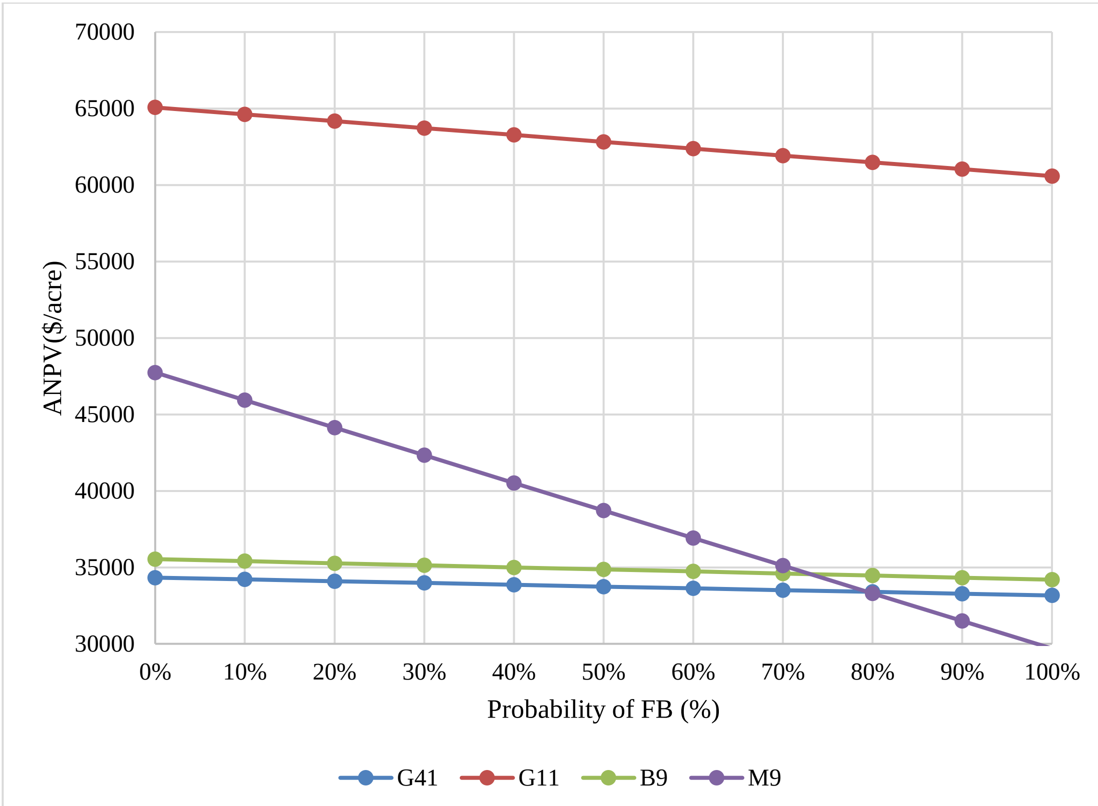

Figure 8-2 ANPV for Fuji, TS for Different Probabilities of Fire Blight, Dressel Farm

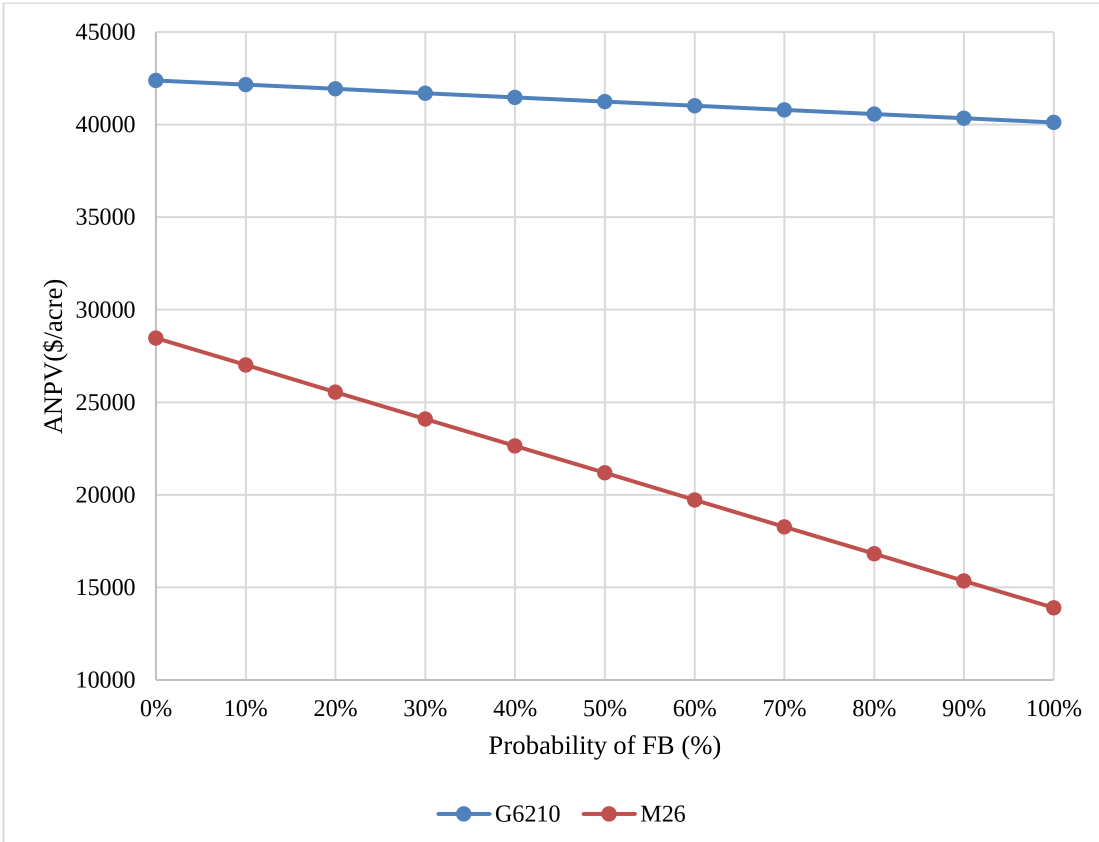

Figure 8-3 ANPV for Fuji, SP for Different Probabilities of Fire Blight, Dressel Farm

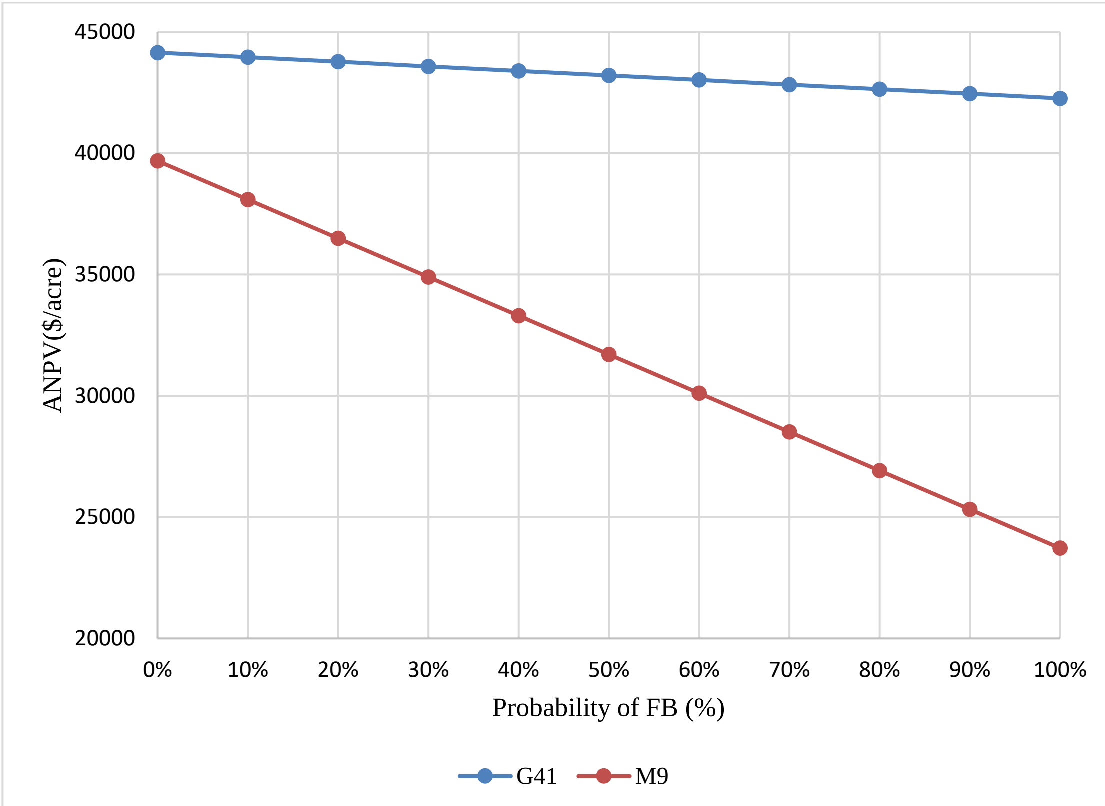

Figure 8-4 ANPV for Fuji, VA for Different Probabilities of Fire Blight, Dressel Farm

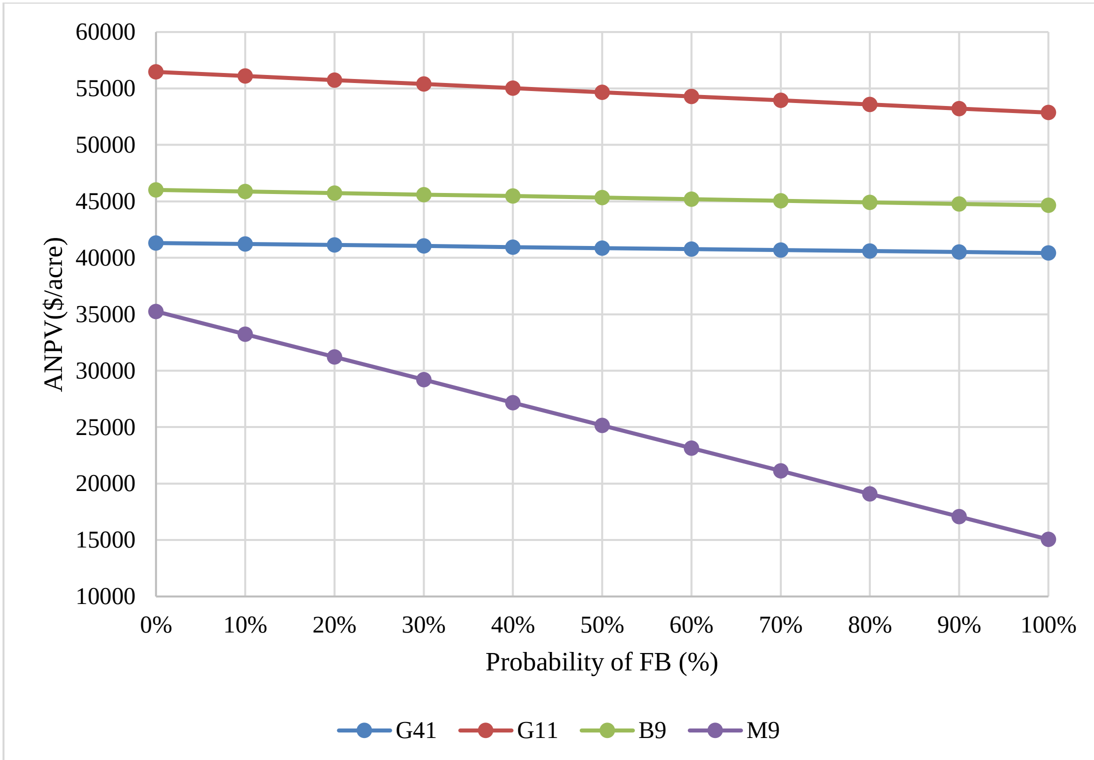

Figure 8-5 ANPV for Gala, SA for Different Probabilities of Fire Blight, Dressel Farm

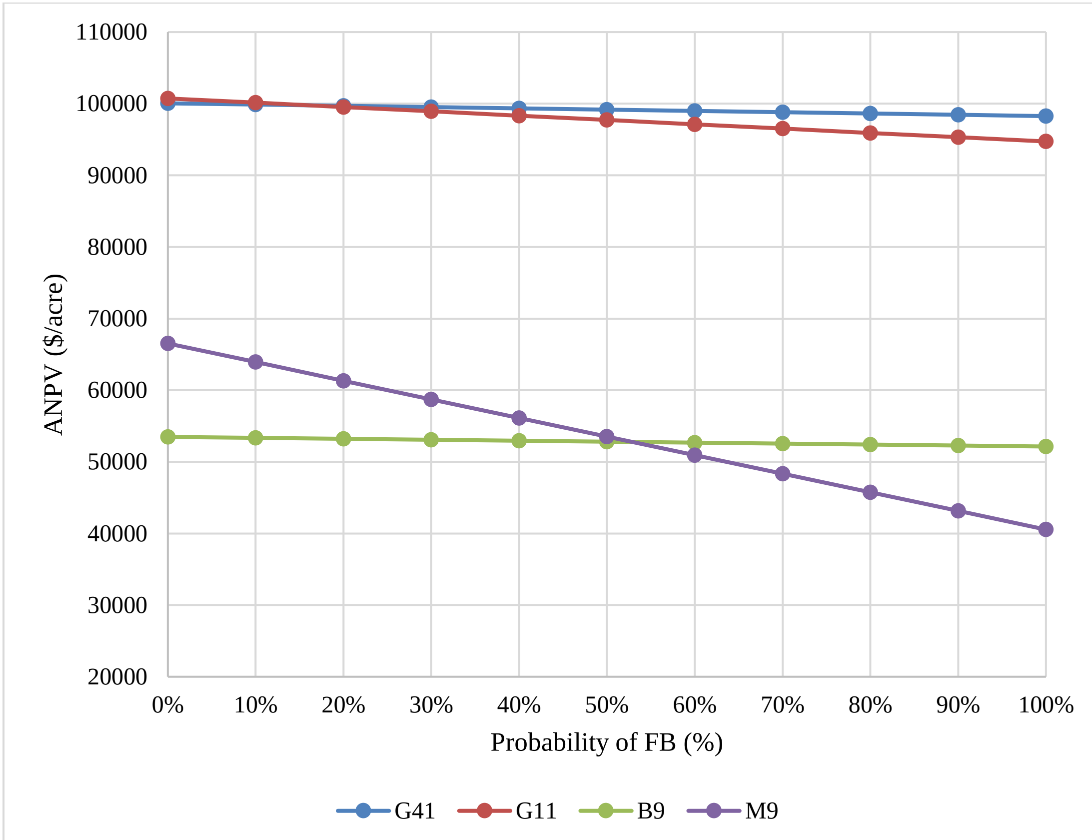

Figure 8-6 ANPV for Gala, TS for Different Probabilities of Fire Blight, Dressel Farm

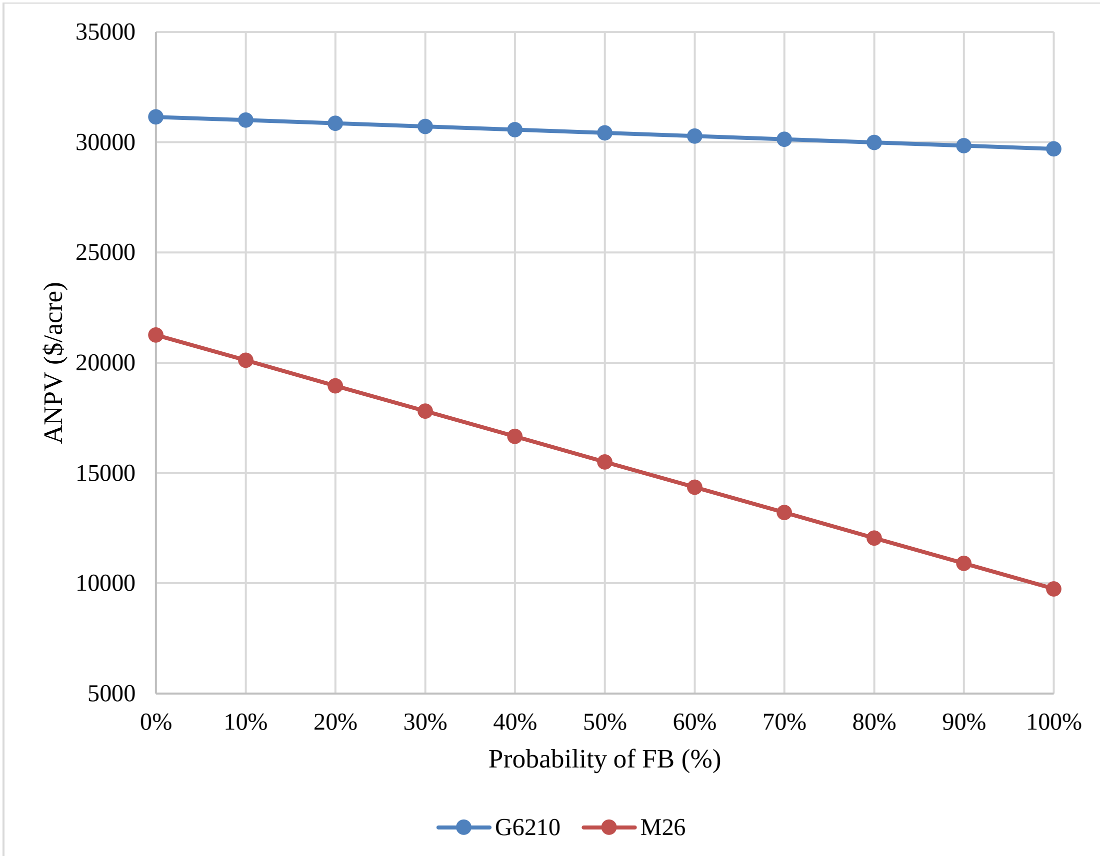

Figure 8-7 ANPV for Gala, SP for Different Probabilities of Fire Blight, Dressel Farm

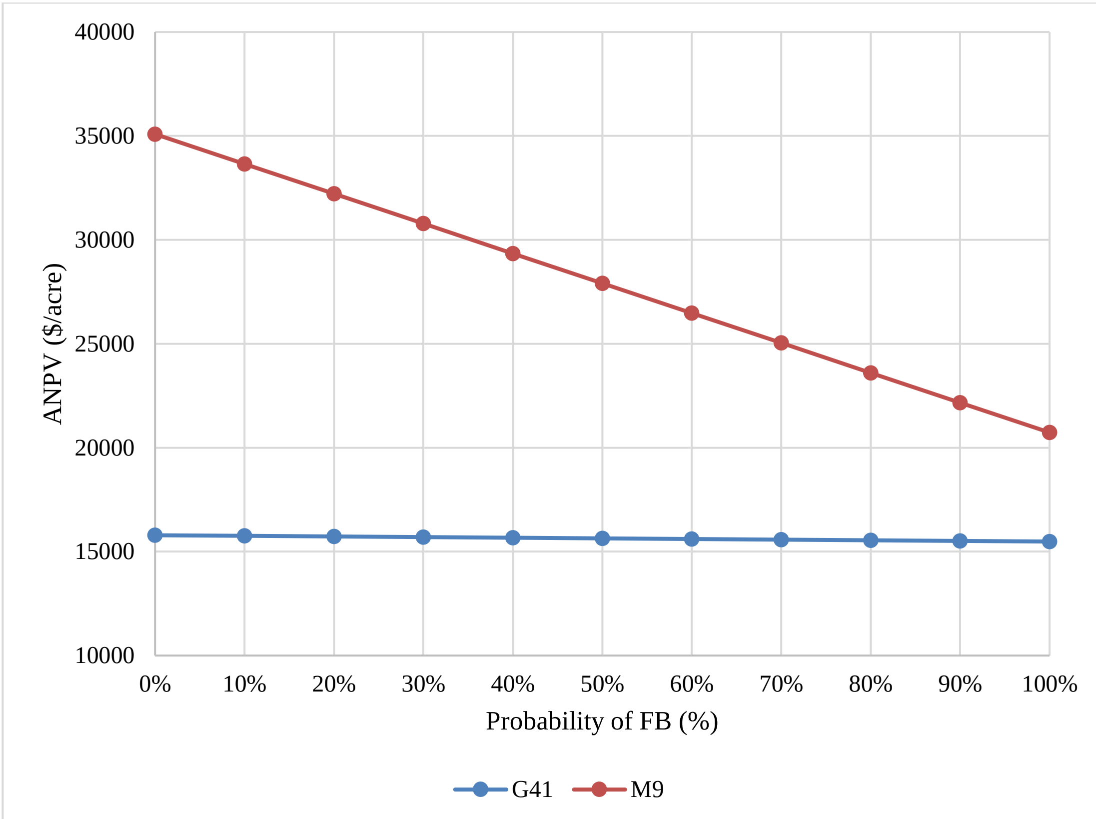

Figure 8-8 ANPV for Gala, VA for Different Probabilities of Fire Blight, Dressel Farm

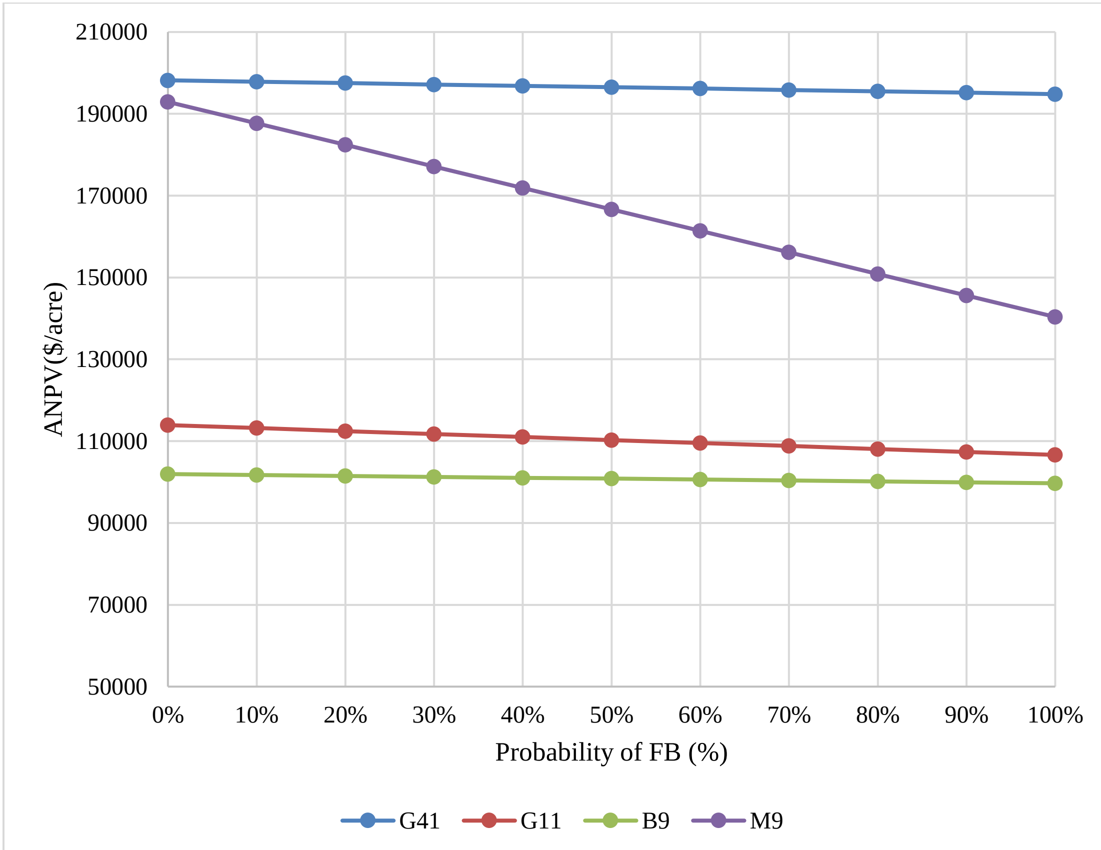

Figure 8-9 ANPV for Gala, SA for Different Probabilities of Fire Blight, VandeWalle Farm

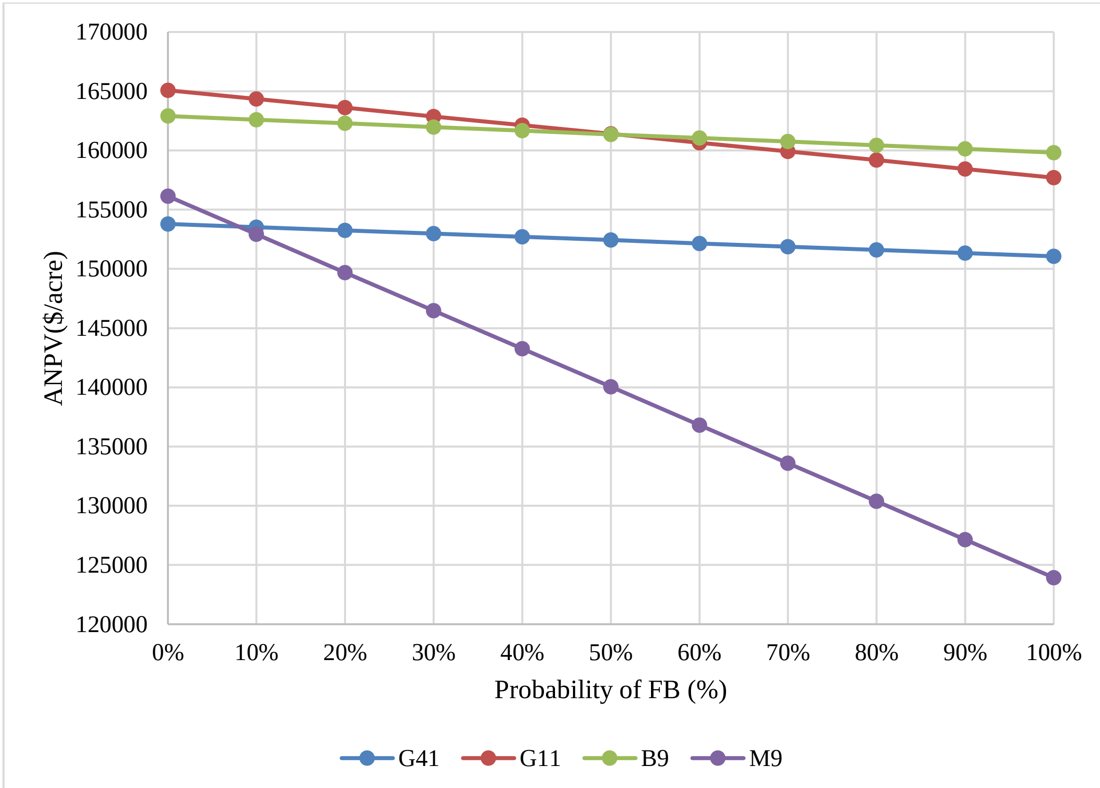

Figure 8-10 ANPV for Gala, TS for Different Probabilities of Fire Blight, VandeWalle Farm

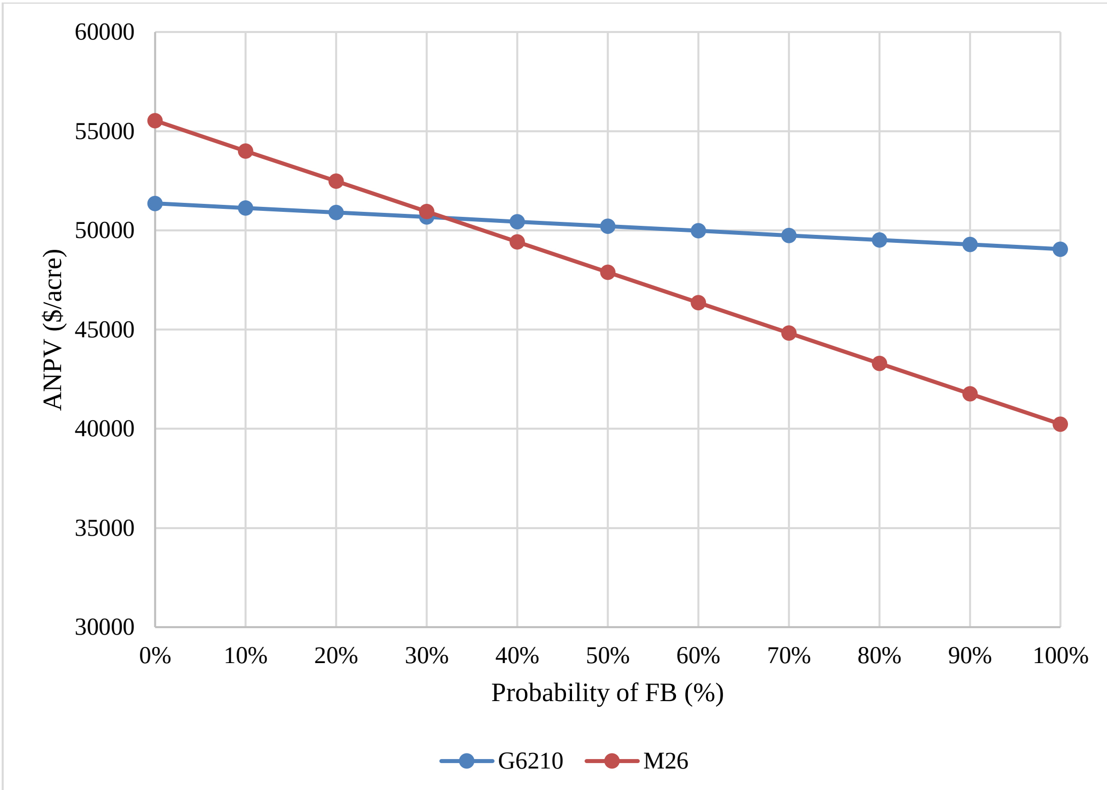

Figure 8-11 ANPV for Gala, SP for Different Probabilities of Fire Blight, VandeWalle Farm

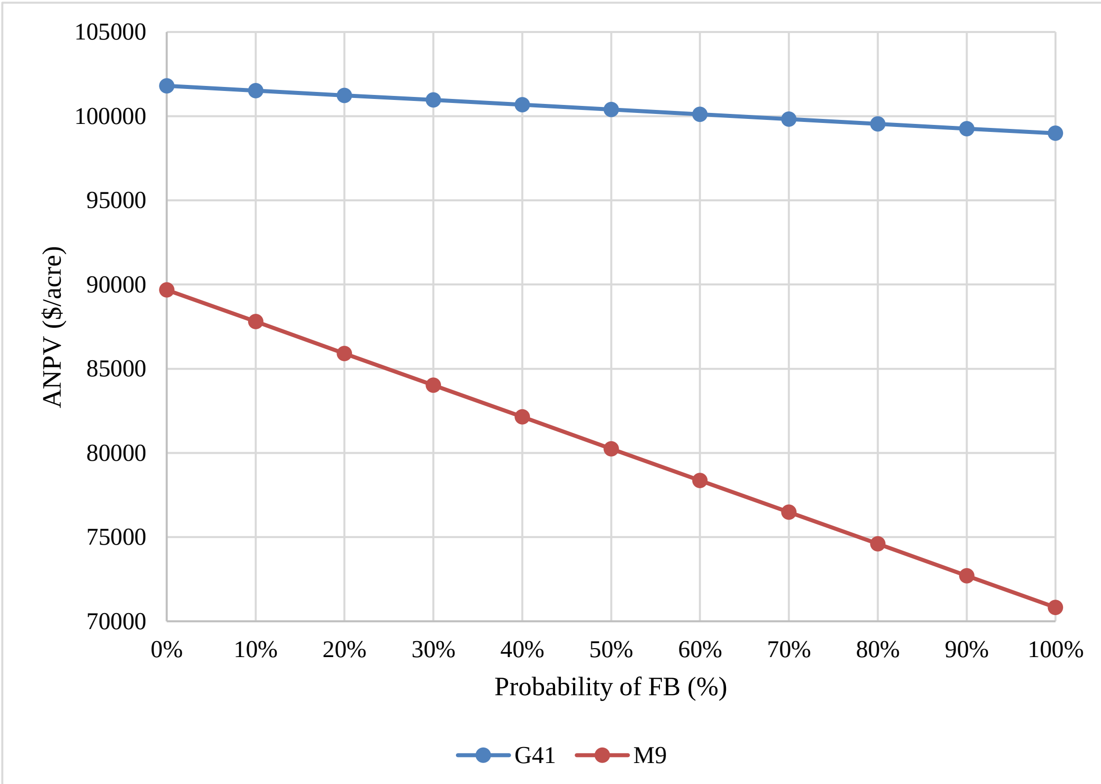

Figure 8-12 ANPV for Gala, VA for Different Probabilities of Fire Blight, VandeWalle Farm

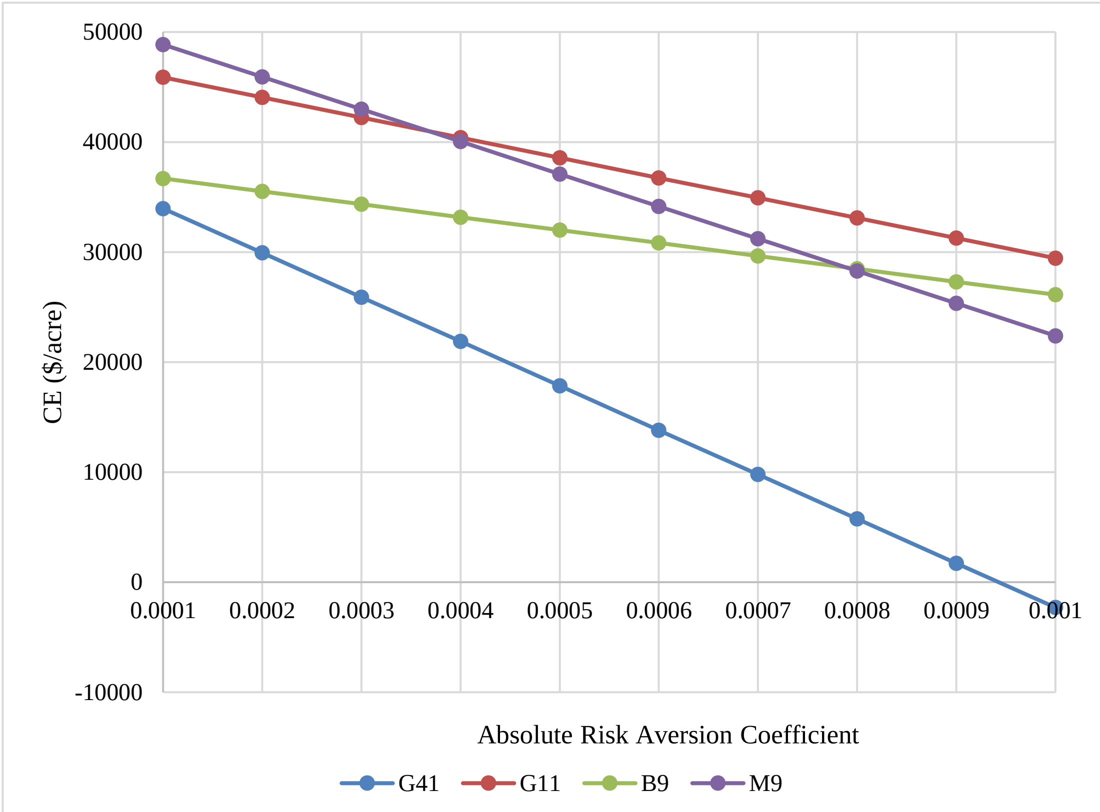

Figure 8-13 Certainty Equivalent under Different CARA for Fuji, SA System, Dressel Farm

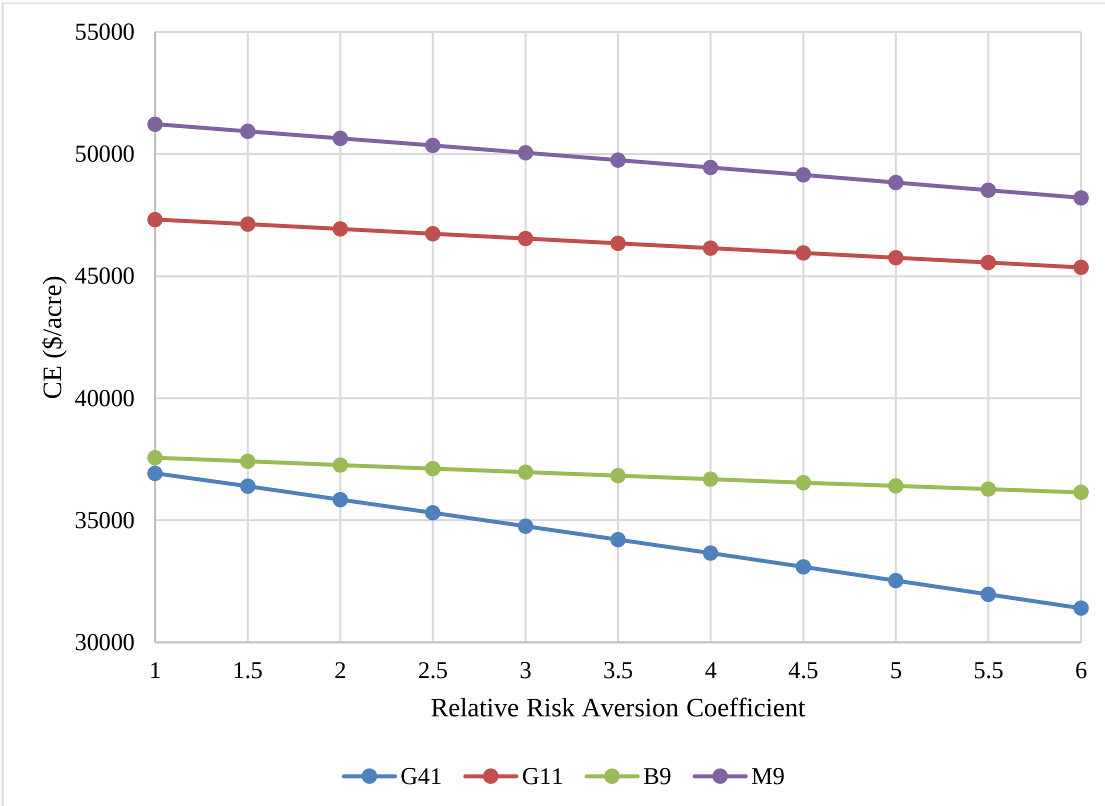

Figure 8-14 Certainty Equivalent under Different CRRA for Fuji, SA System, Dressel Farm

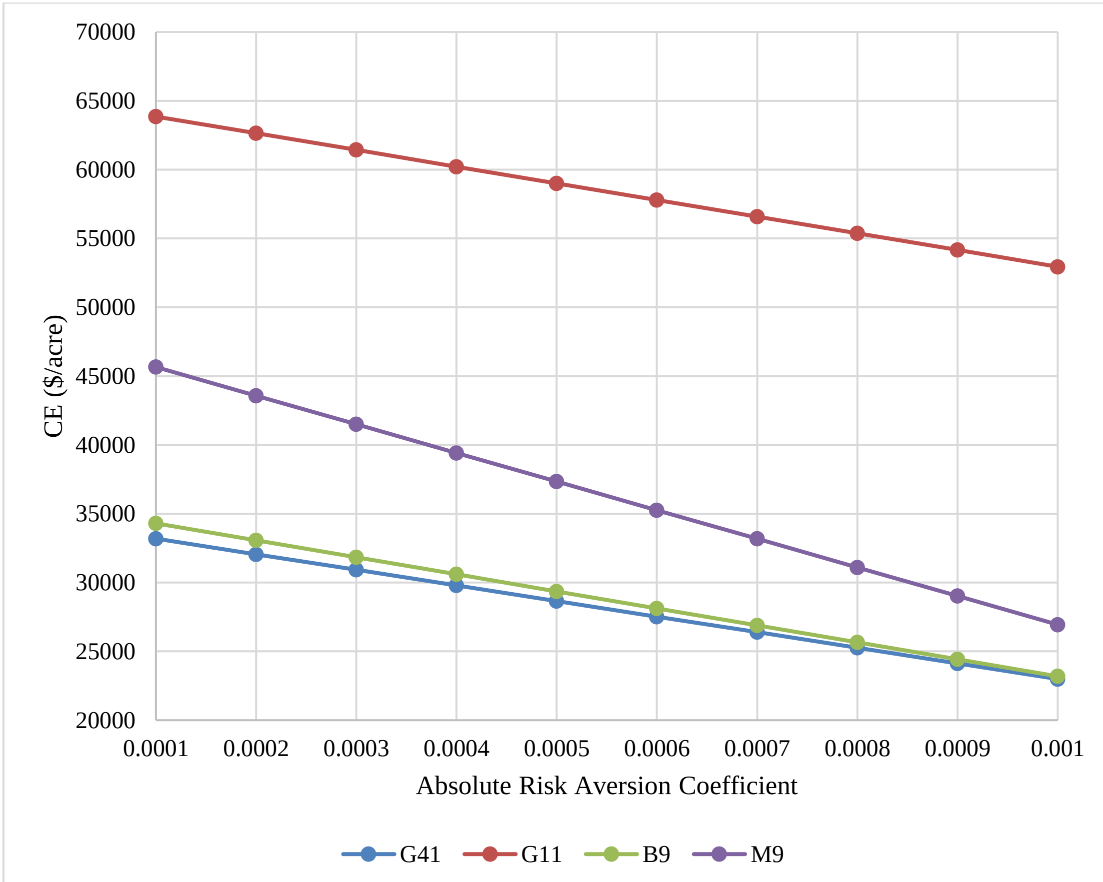

Figure 8-15 Certainty Equivalent under Different CARA for Fuji, TS System, Dressel Farm

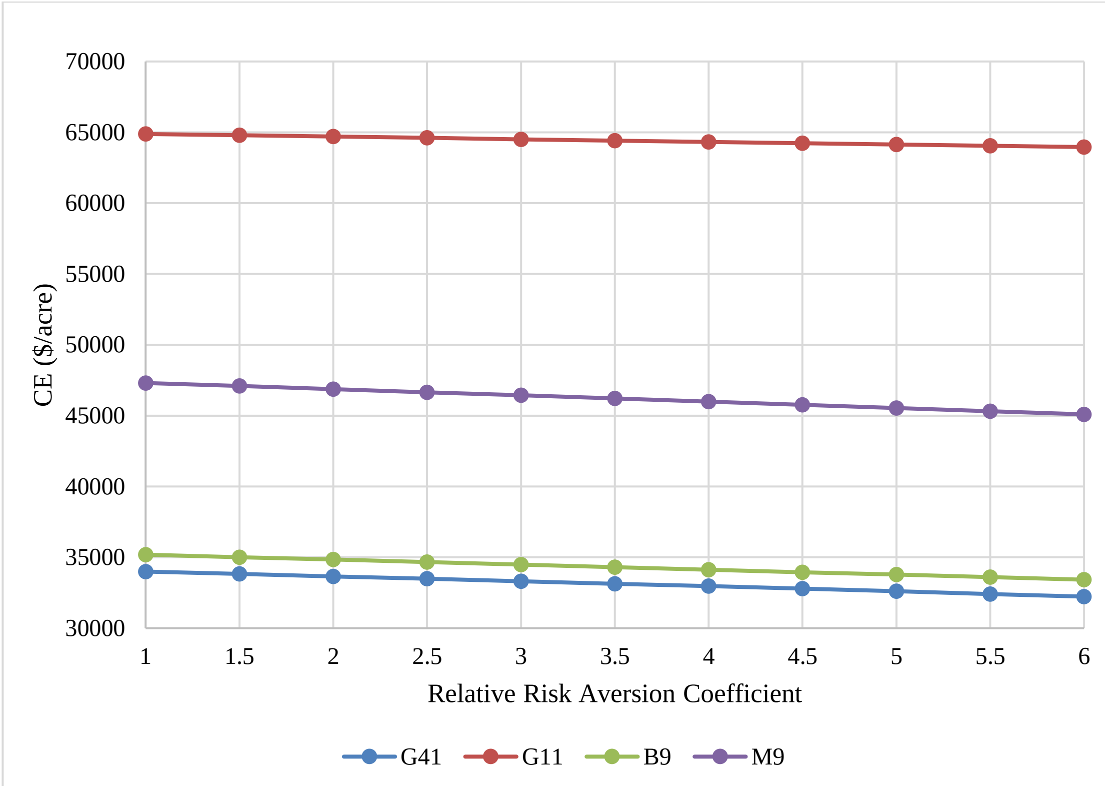

Figure 8-16 Certainty Equivalent under Different CRRA for Fuji, TS System, Dressel Farm

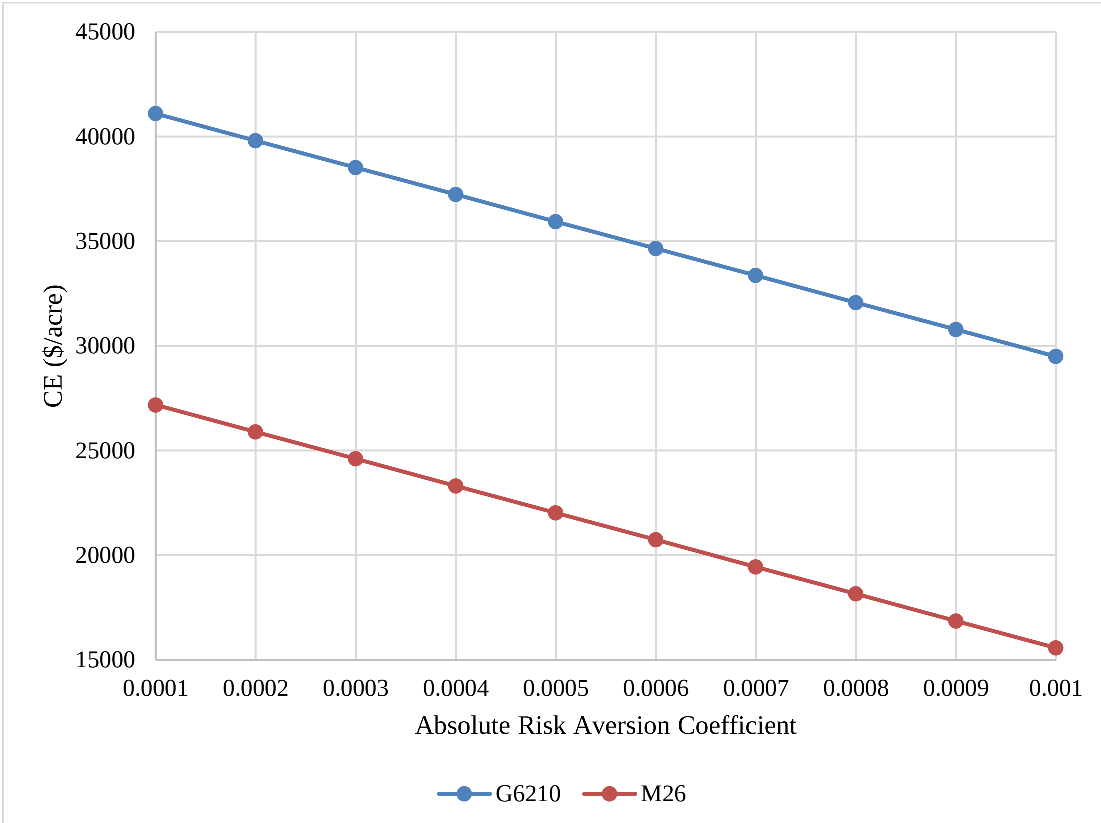

Figure 8-17 Certainty Equivalent under Different CARA for Fuji, SP System, Dressel Farm

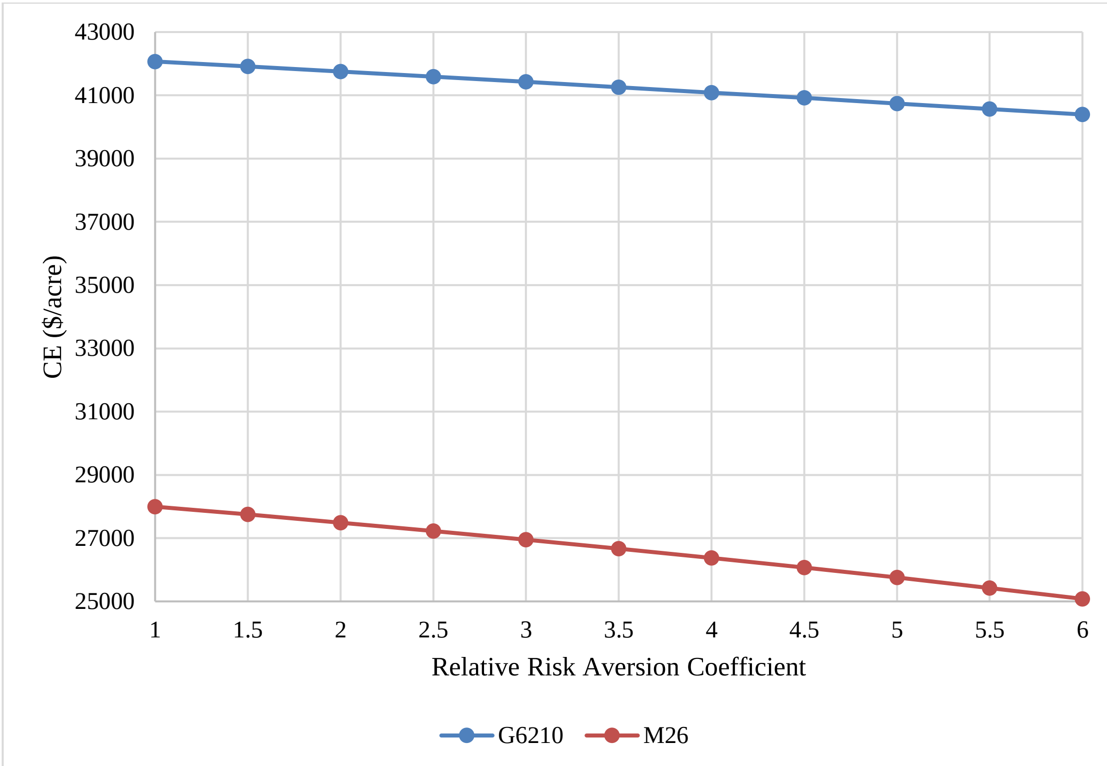

Figure 8-18 Certainty Equivalent under Different CRRA for Fuji, SP System, Dressel Farm

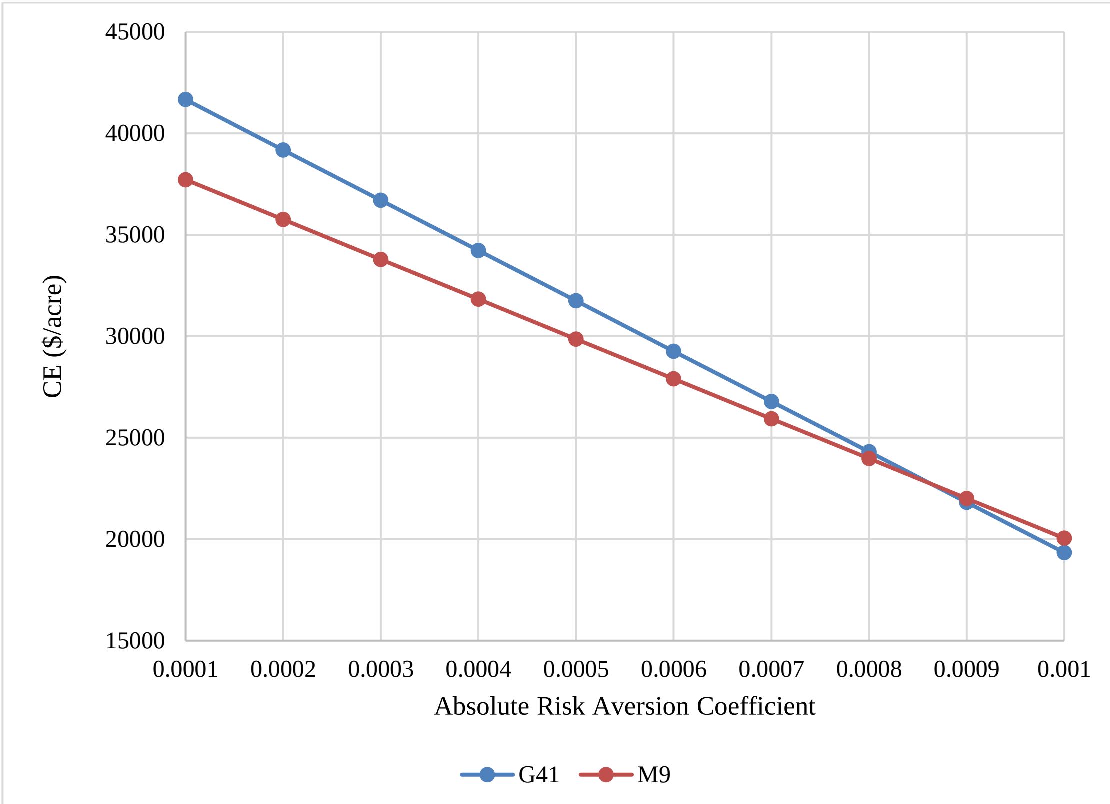

Figure 8-19 Certainty Equivalent under Different CARA for Fuji, VA System, Dressel Farm

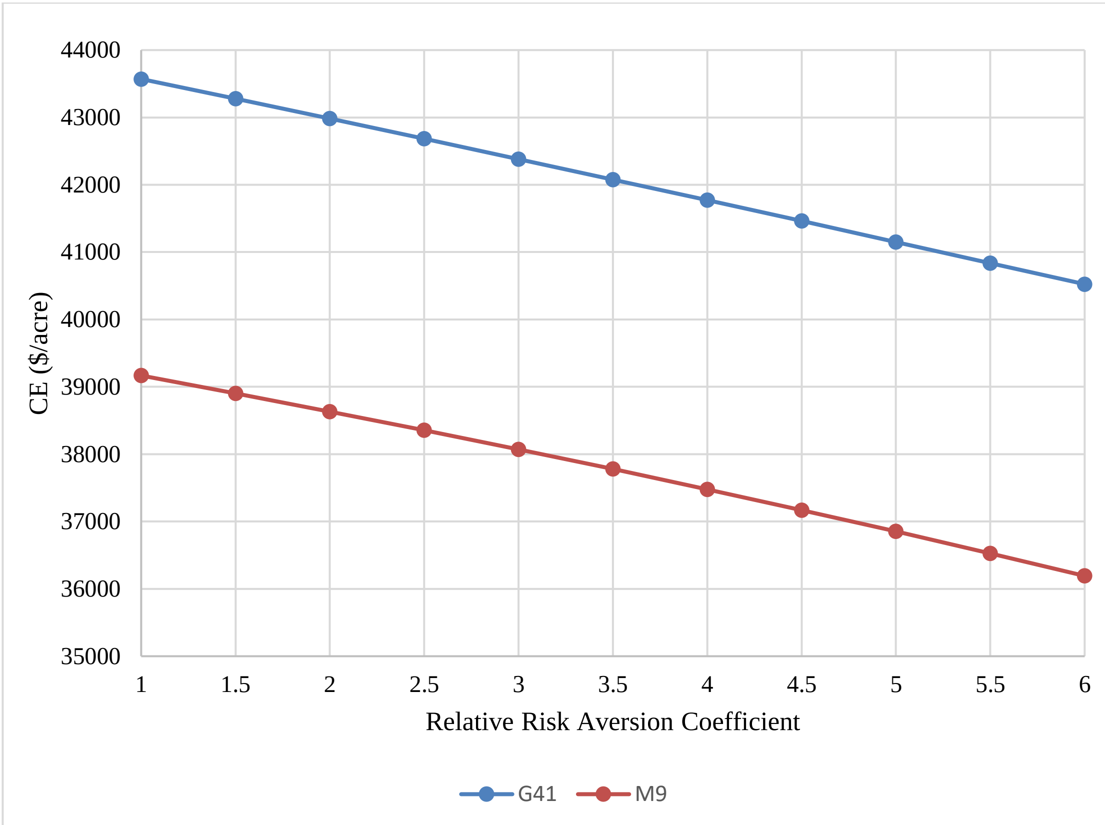

Figure 8-20 Certainty Equivalent under Different CRRA for Fuji, VA System, Dressel Farm

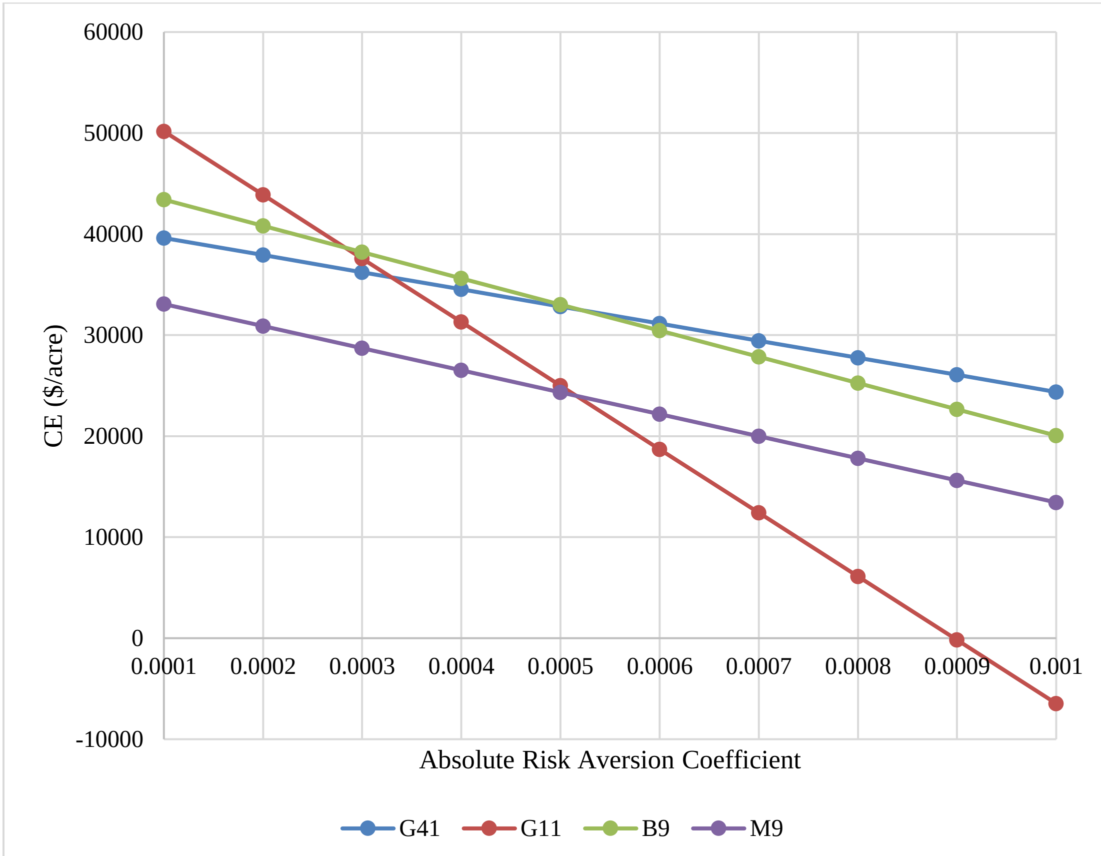

Figure 8-21 Certainty Equivalent under Different CARA for Gala, SA System, Dressel Farm

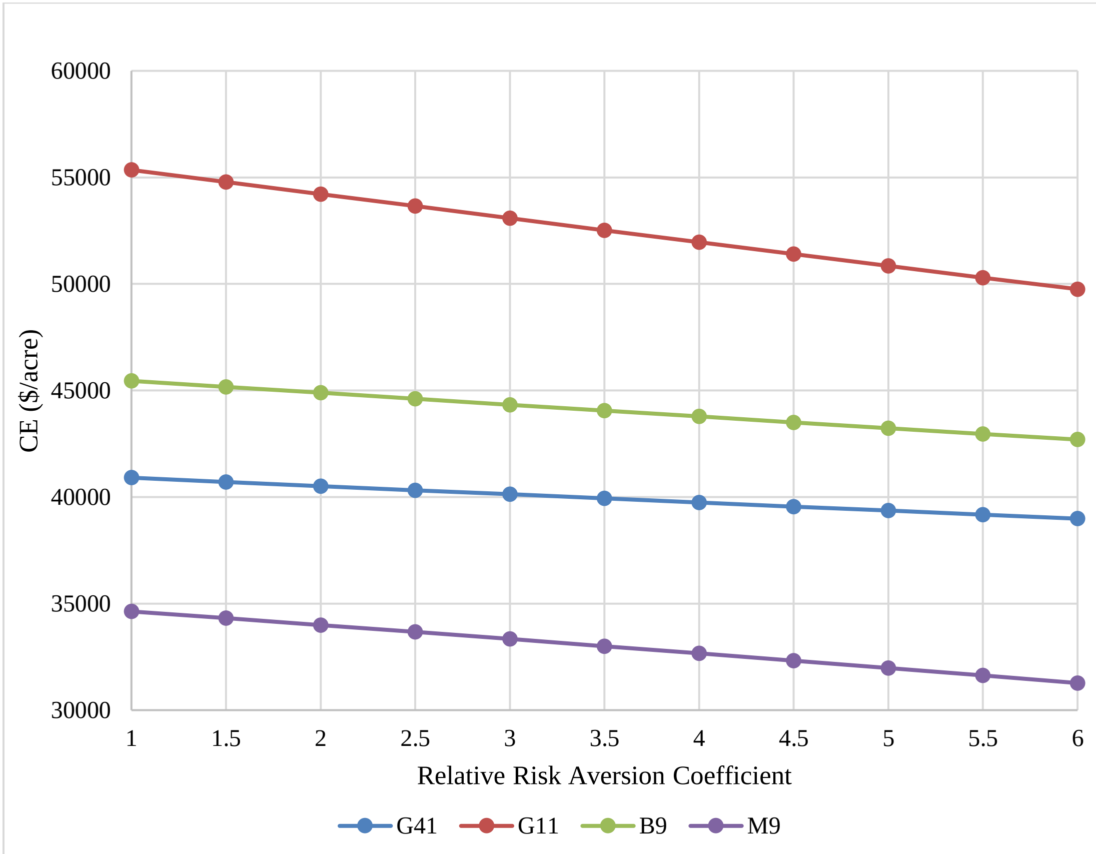

Figure 8-22 Certainty Equivalent under Different CRRA for Gala, SA System, Dressel Farm

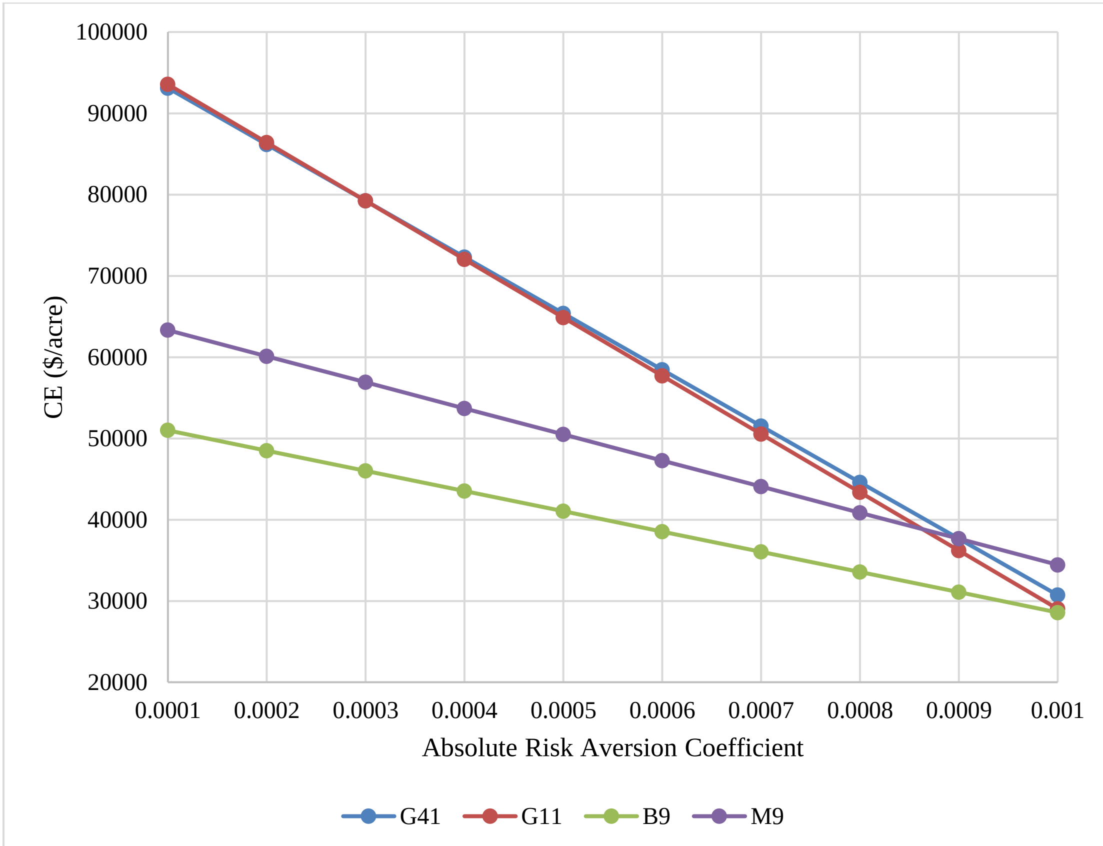

Figure 8-23 Certainty Equivalent under Different CARA for Gala, TS System, Dressel Farm

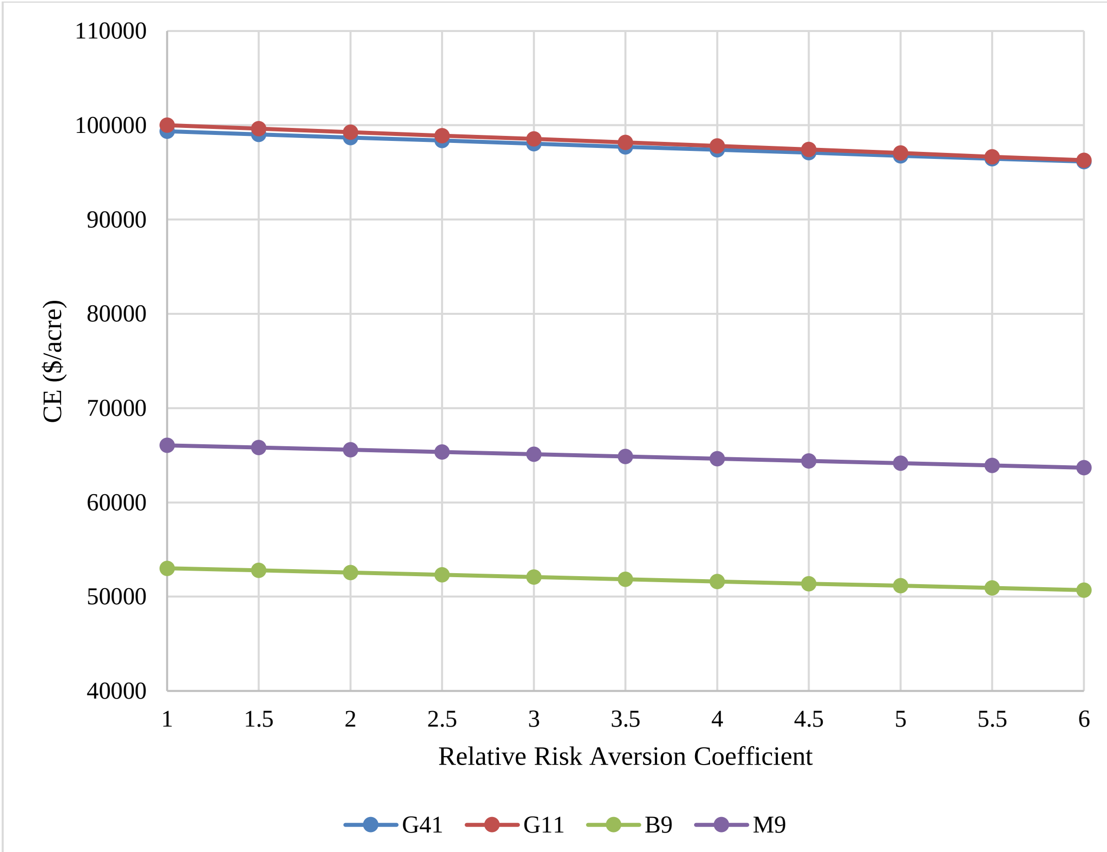

Figure 8-24 Certainty Equivalent under Different CRRA for Gala, TS System, Dressel Farm

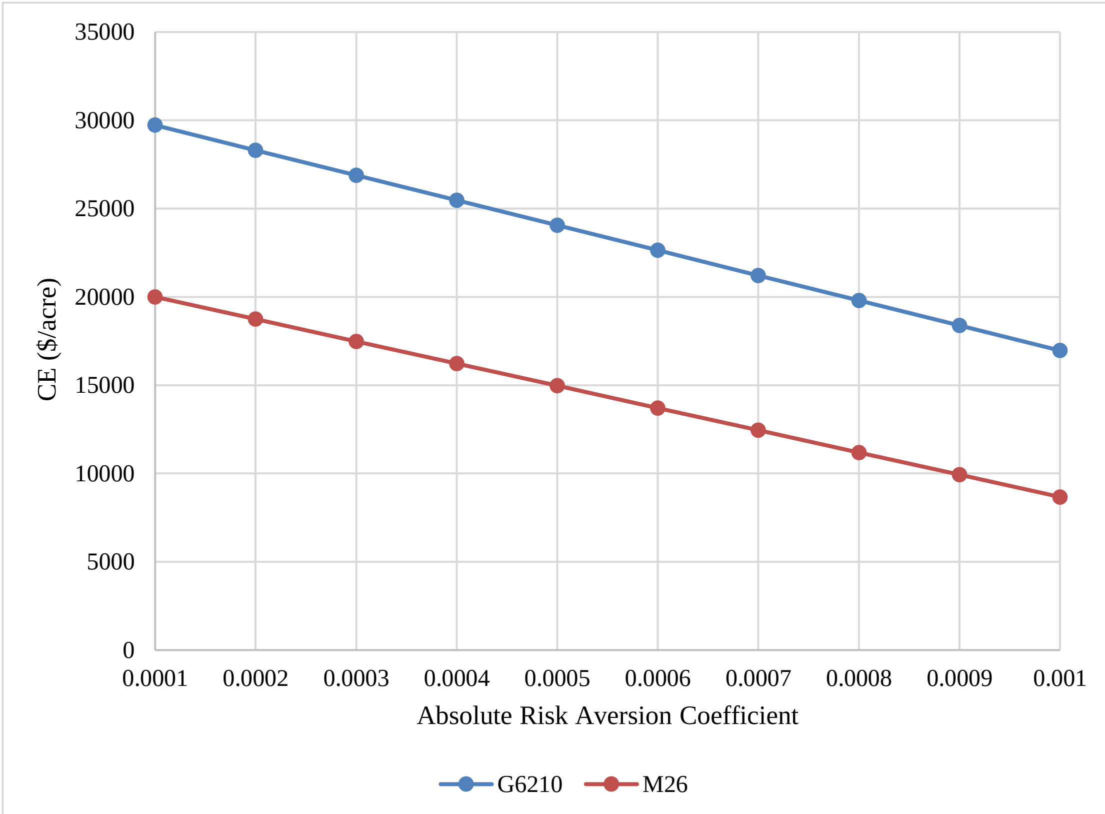

Figure 8-25 Certainty Equivalent under Different CARA for Gala, SP System, Dressel Farm

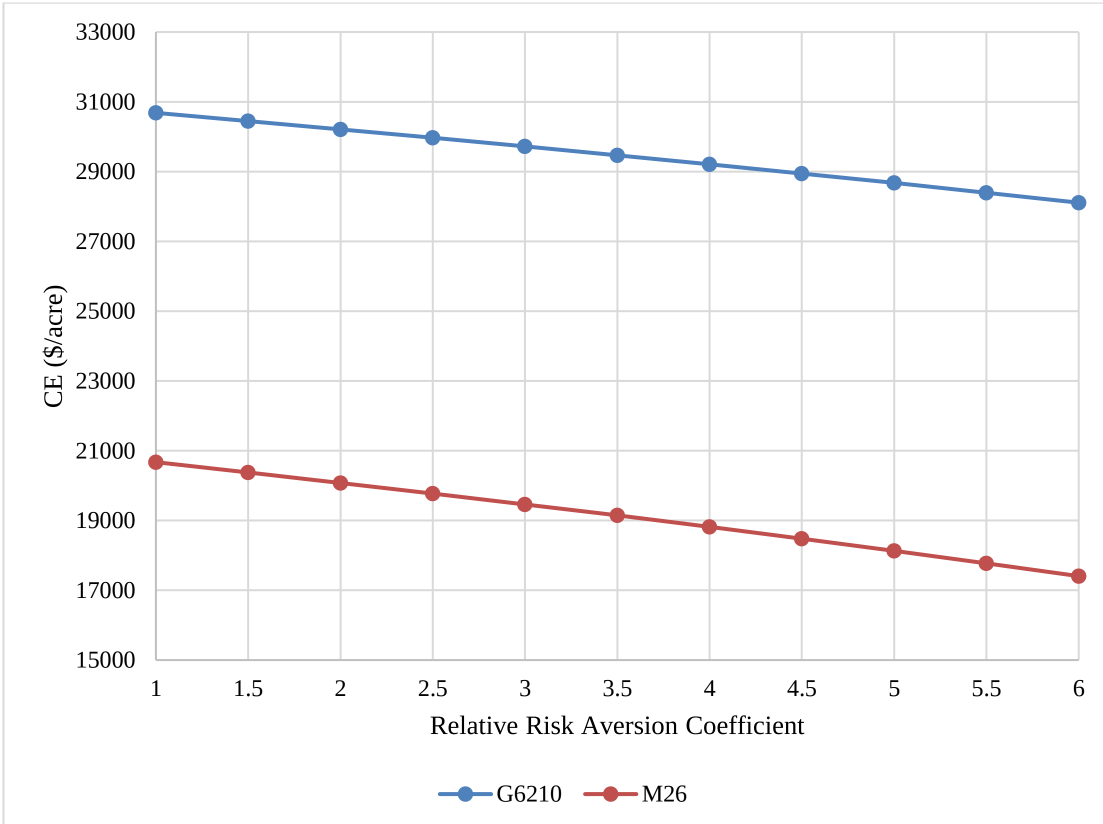

Figure 8-26 Certainty Equivalent under Different CRRA for Gala, SP System, Dressel Farm

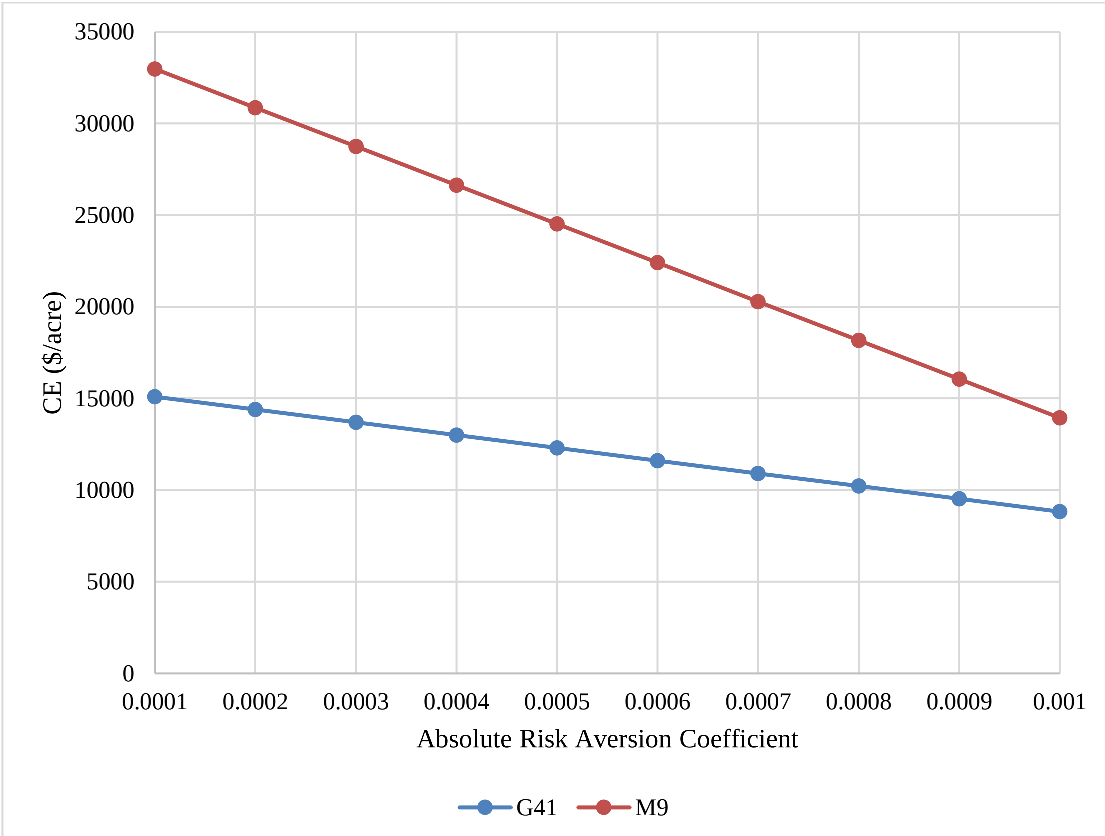

Figure 8-27 Certainty Equivalent under Different CARA for Gala, VA System, Dressel Farm

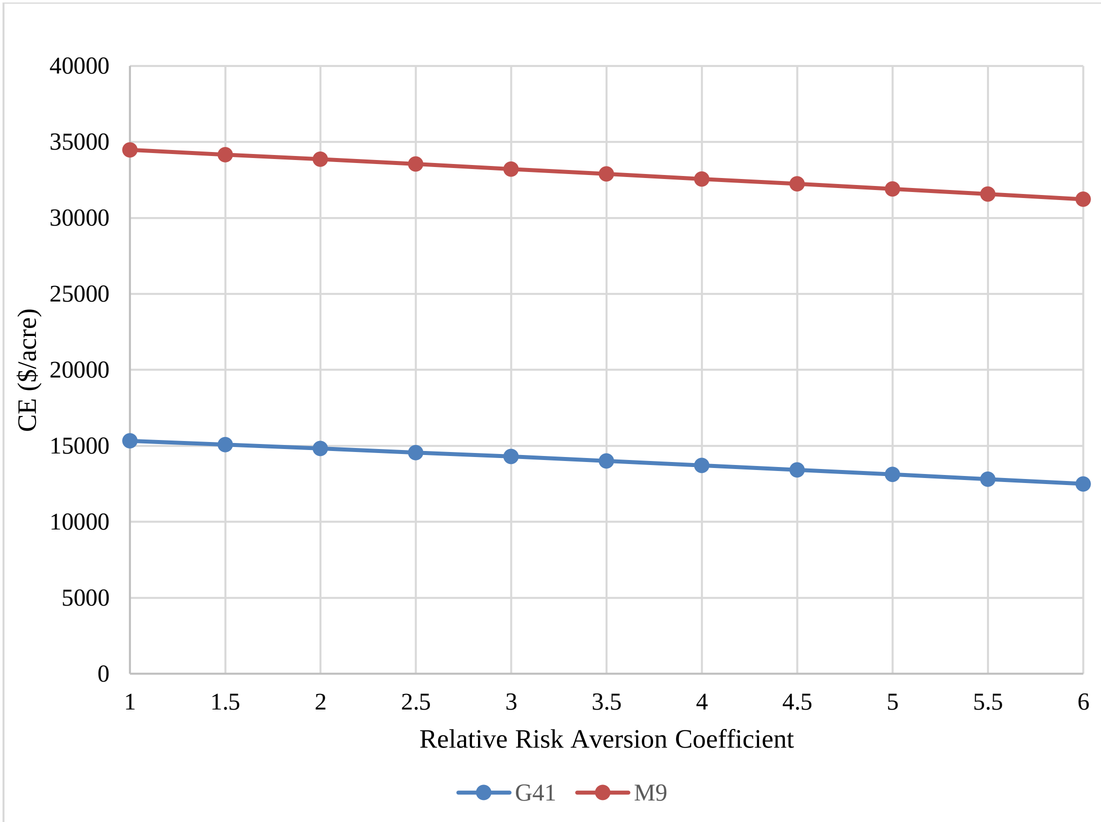

Figure 8-28 Certainty Equivalent under Different CRRA for Gala, VA System, Dressel Farm

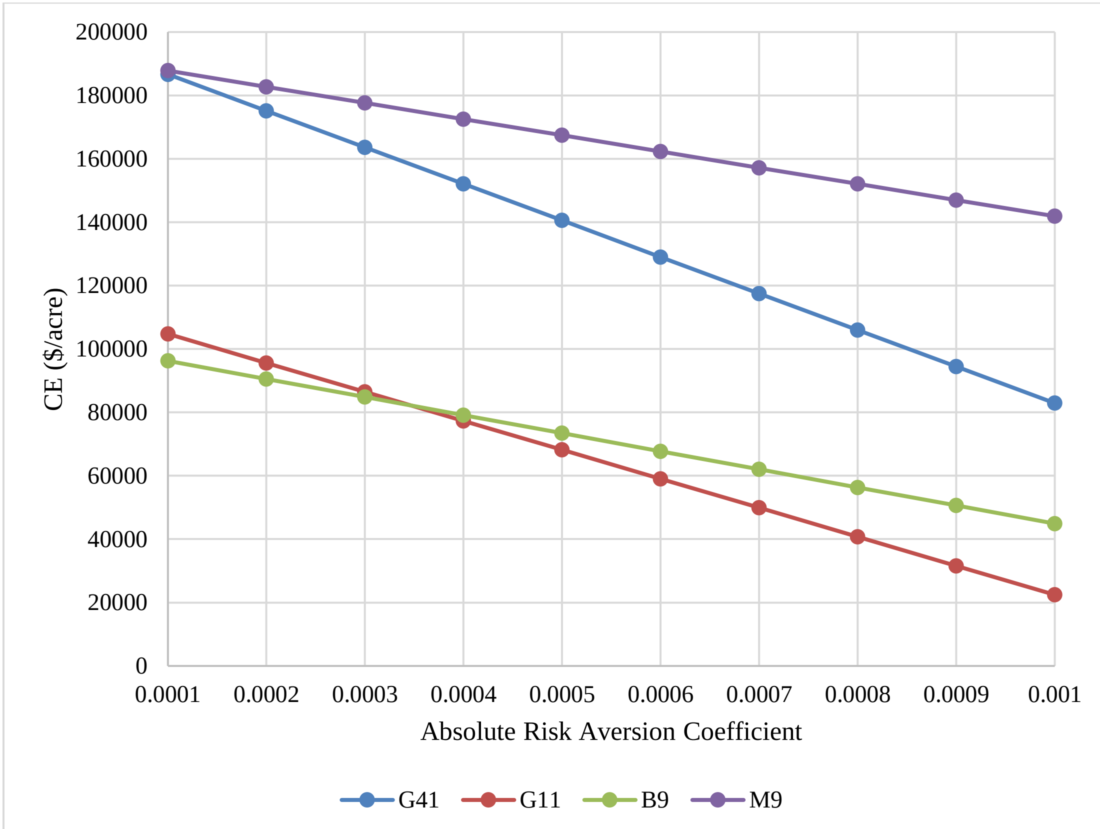

Figure 8-29 Certainty Equivalent under Different CARA for Gala, SA System, VandeWalle Farm

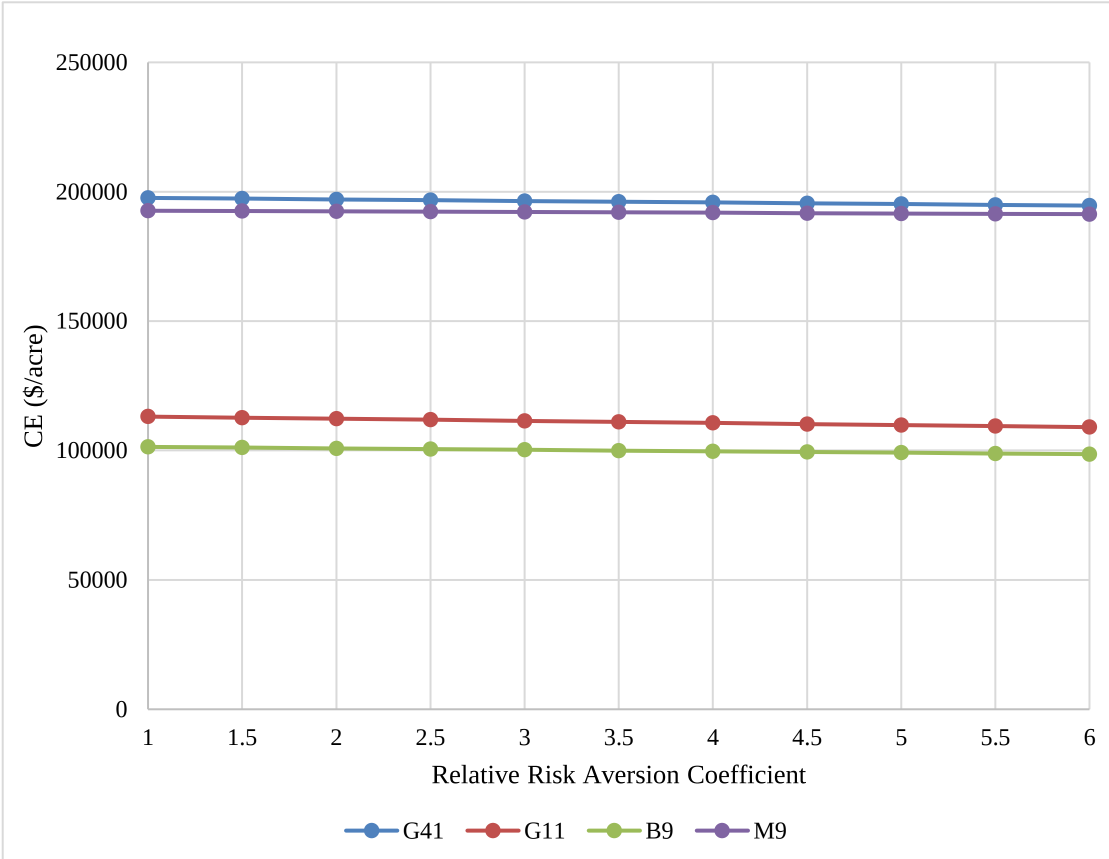

Figure 8-30 Certainty Equivalent under Different CRRA for Gala, SA System, VandeWalle Farm

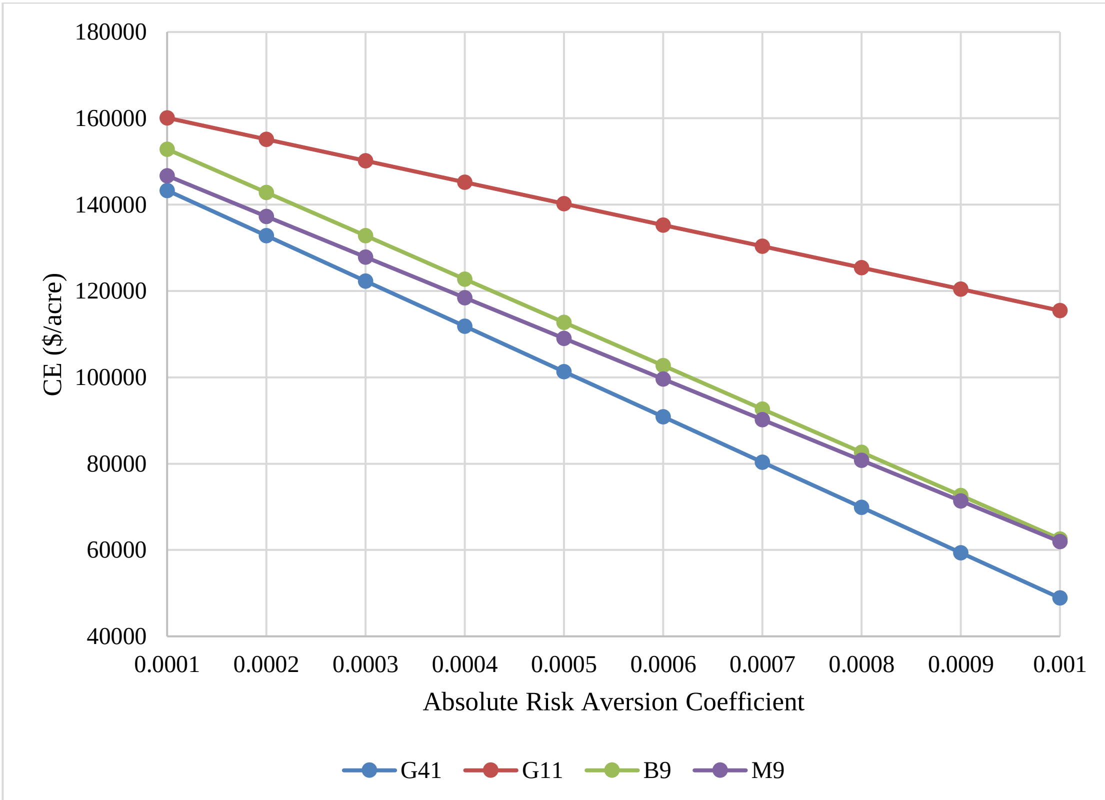

Figure 8-31 Certainty Equivalent under Different CARA for Gala, TS System, VandeWalle Farm

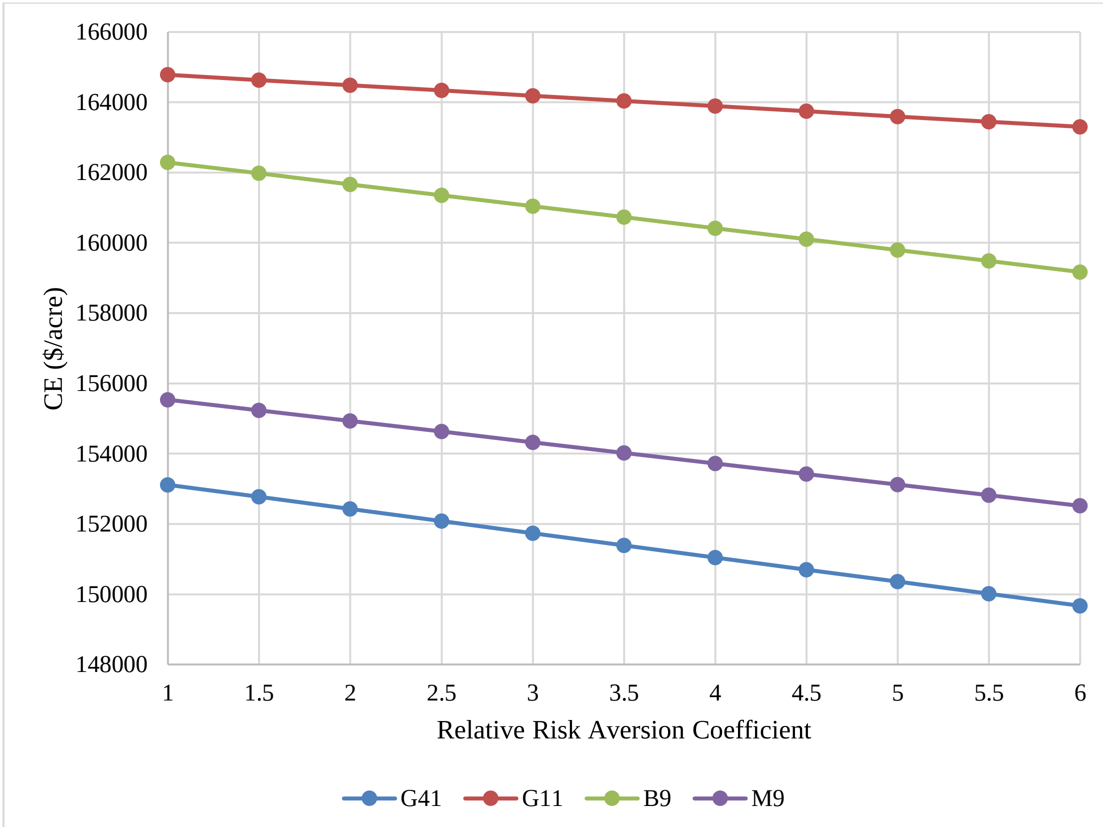

Figure 8-32 Certainty Equivalent under Different CRRA for Gala, TS System, VandeWalle Farm

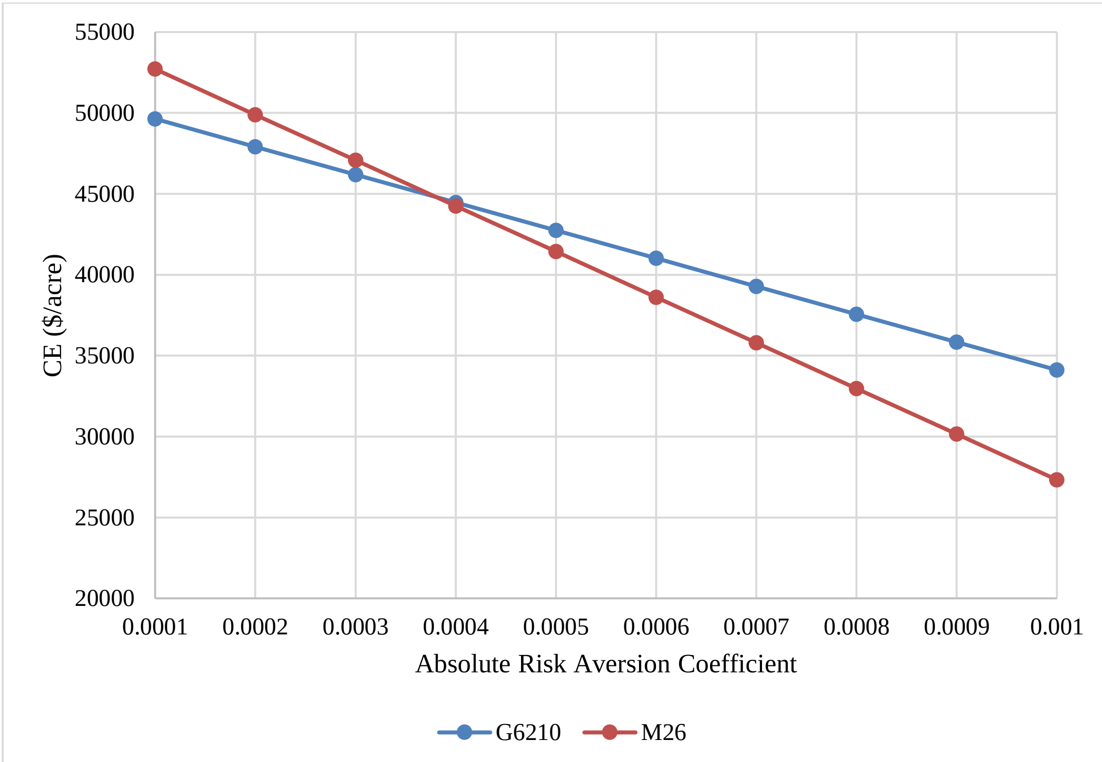

Figure 8-33 Certainty Equivalent under Different CARA for Gala, SP System, VandeWalle Farm

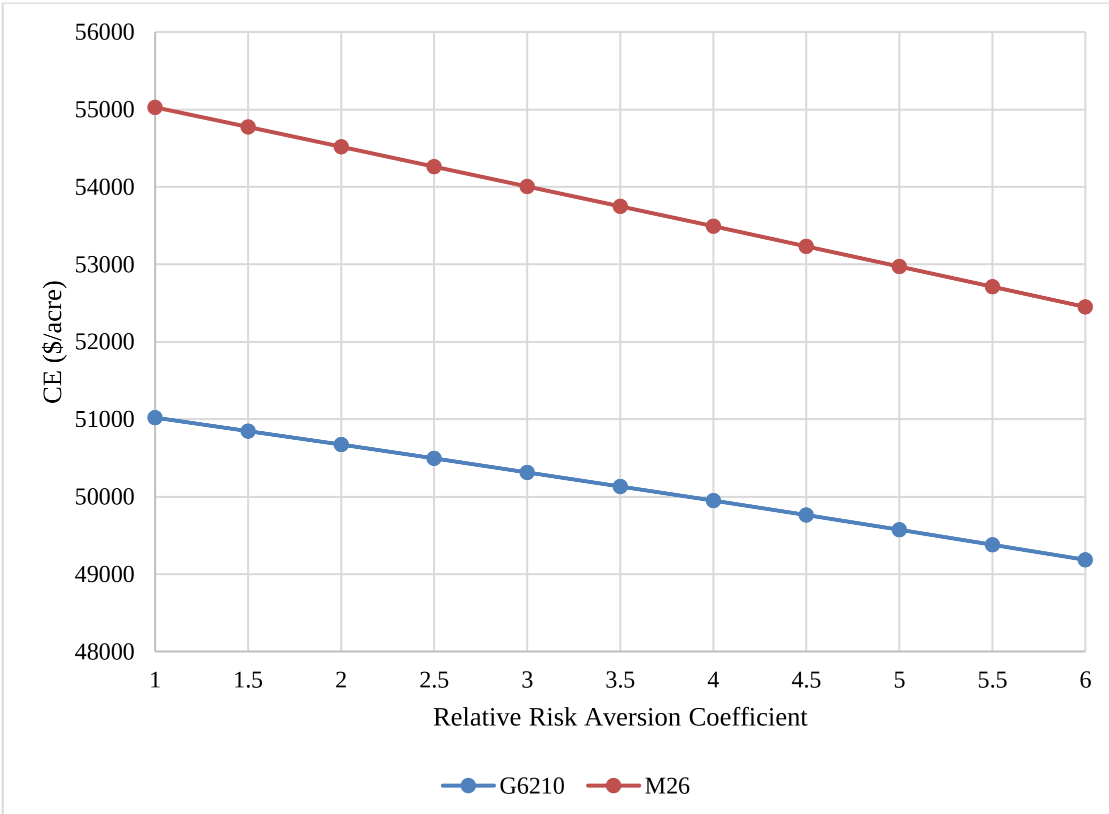

Figure 8-34 Certainty Equivalent under Different CRRA for Gala, SP System, VandeWalle Farm

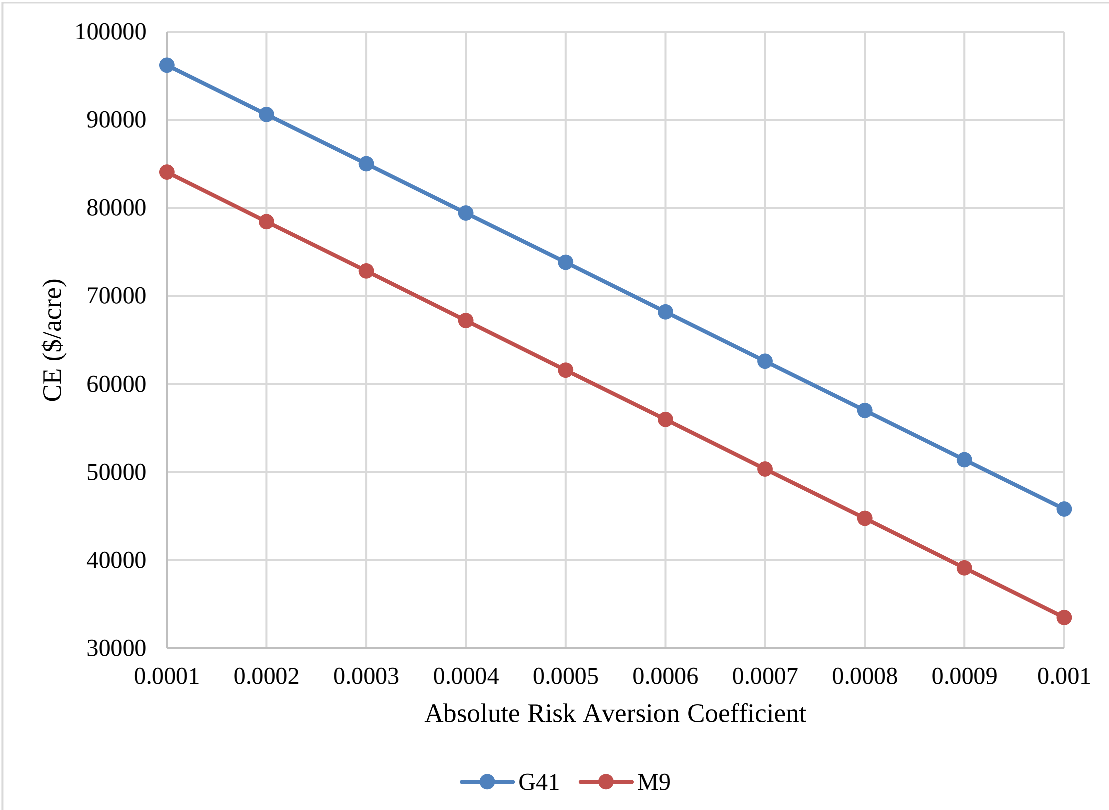

Figure 8-35 Certainty Equivalent under Different CARA for Gala, VA System, VandeWalle Farm

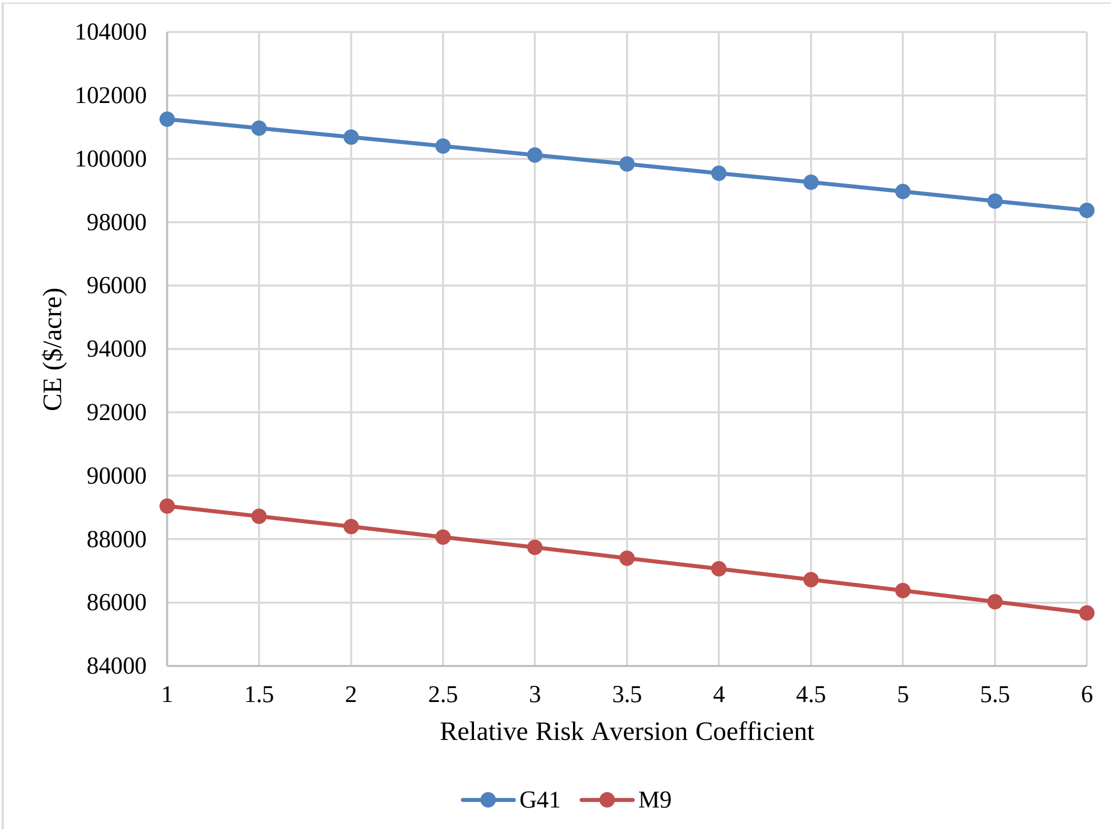

Figure 8-36 Certainty Equivalent under Different CRRA for Gala, VA System, VandeWalle Farm

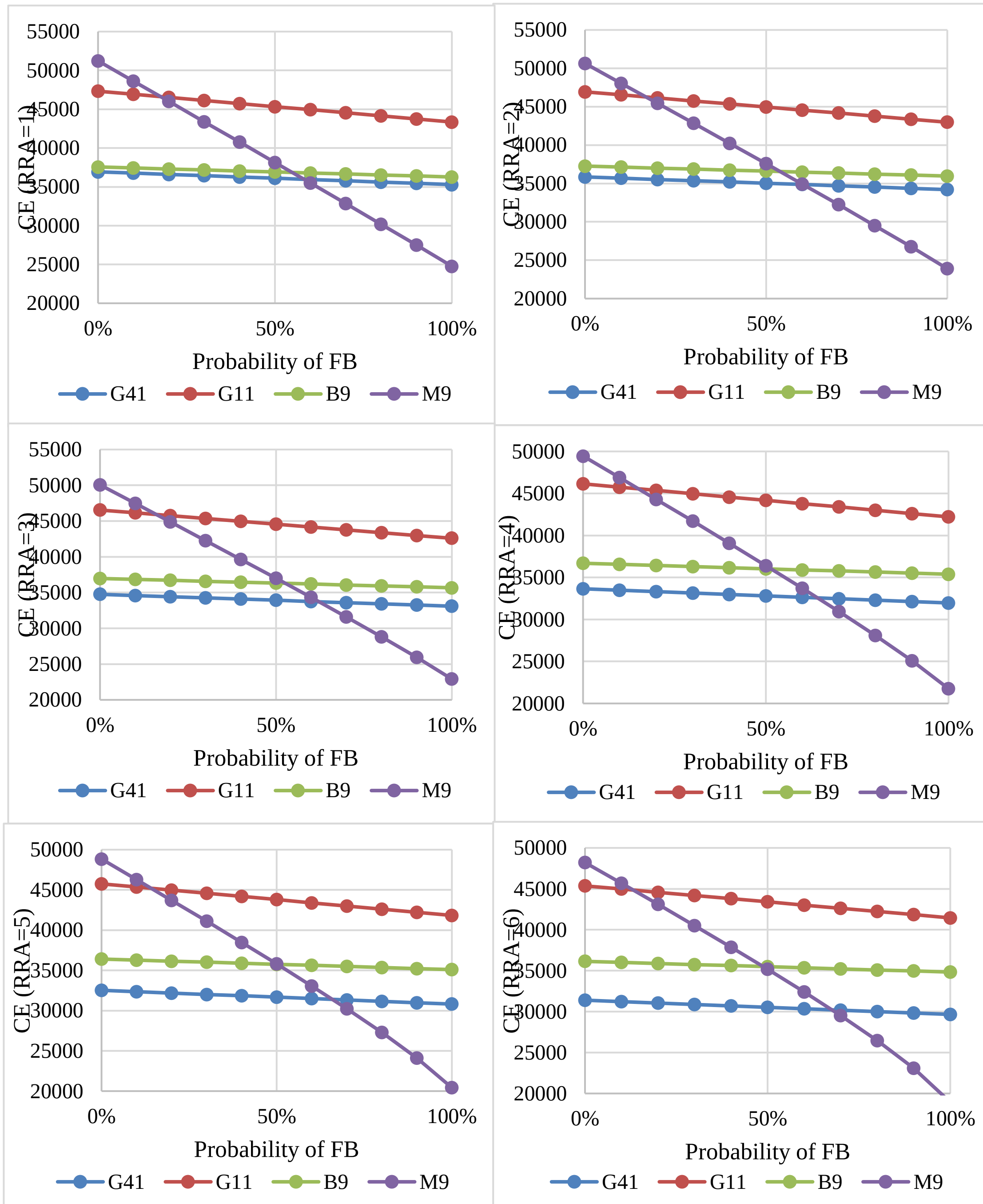

Figure 8-37 Certainty Equivalent under Different CRRA for Fuji, SA System, Dressel Farm for Different Probability of Fire Blight

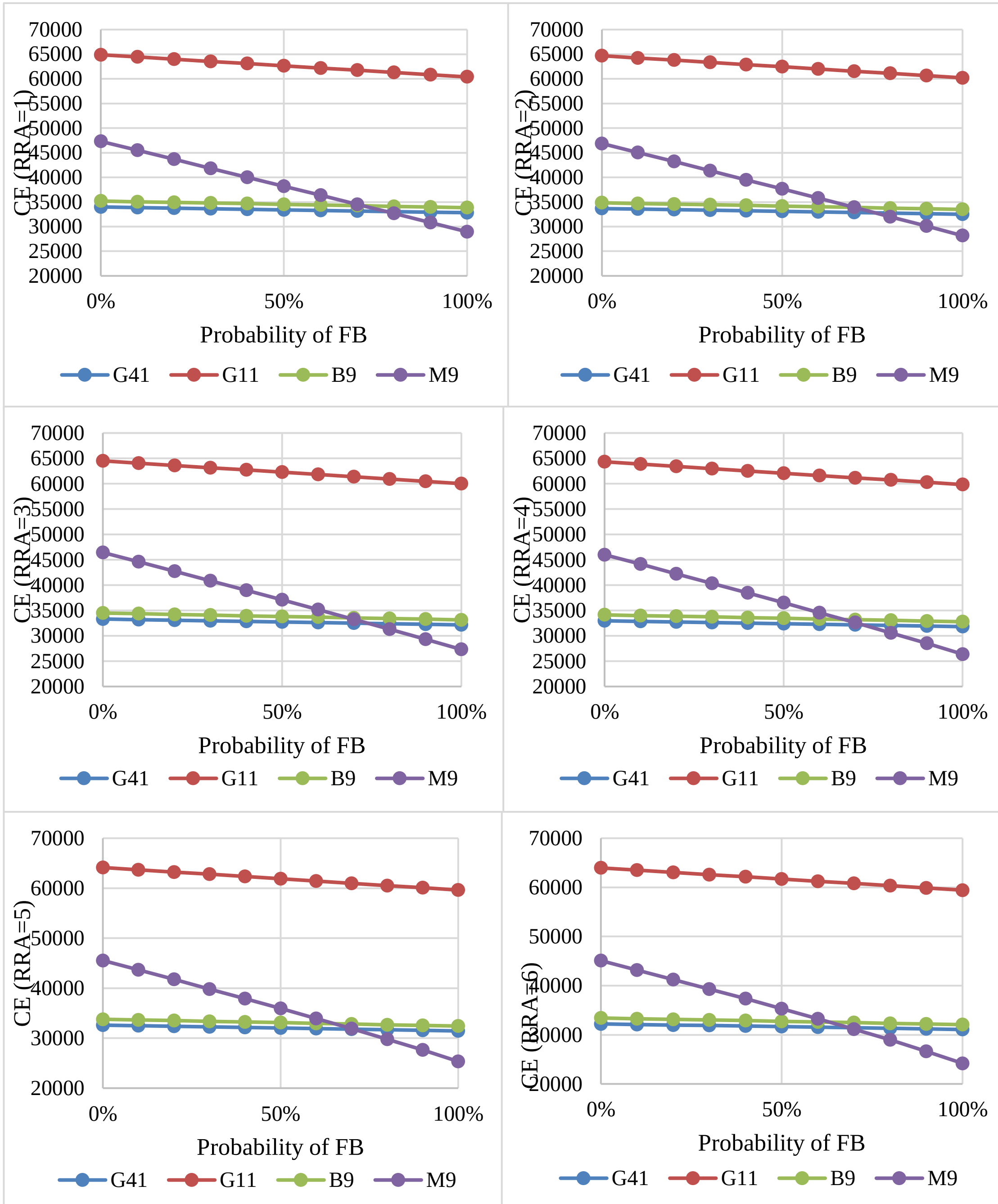

Figure 8-38 Certainty Equivalent under Different CRRA for Fuji, TS System, Dressel Farm for Different Probability of Fire Blight

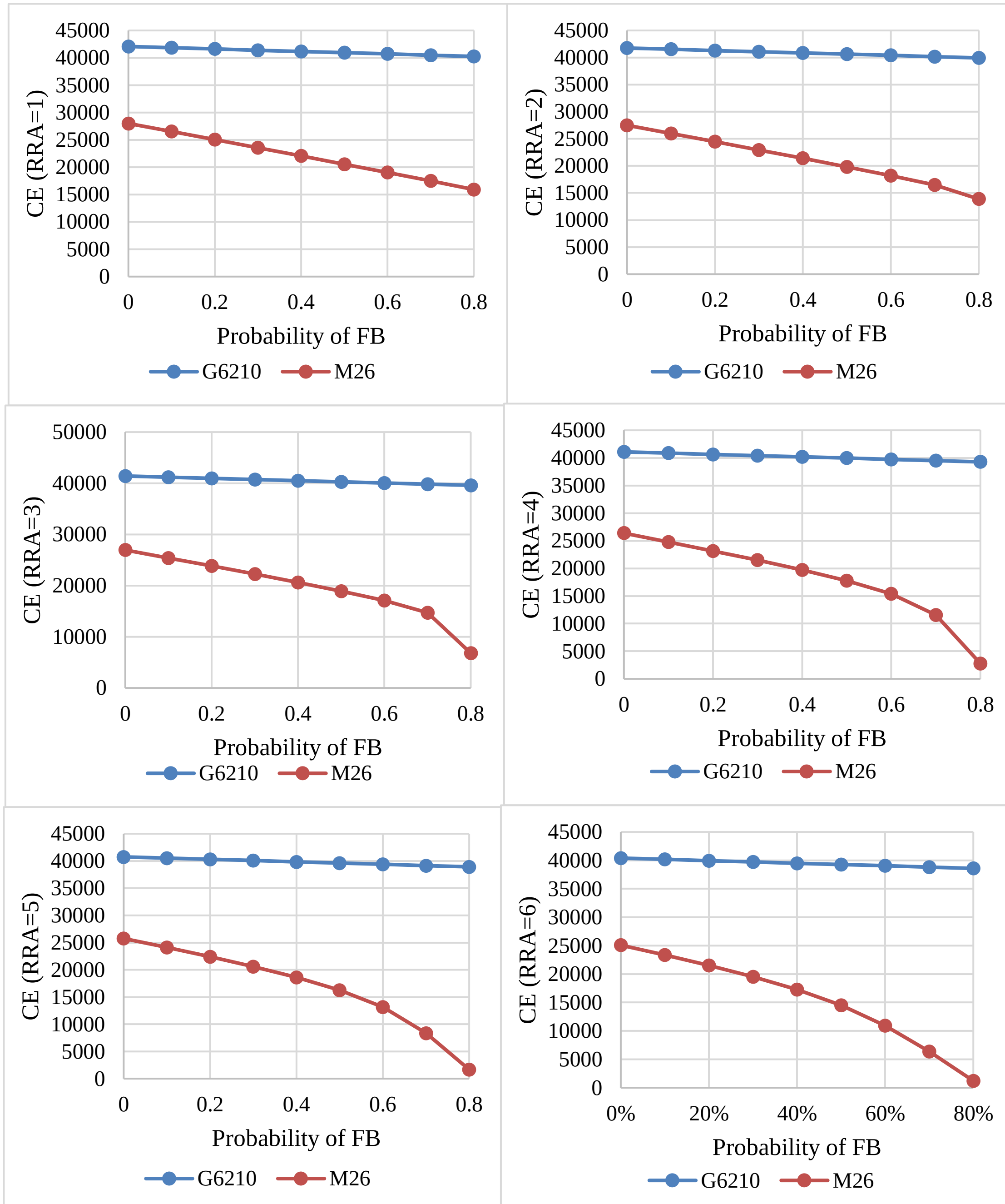

Figure 8-39 Certainty Equivalent under Different CRRA for Fuji, SP System, Dressel Farm for Different Probability of Fire Blight

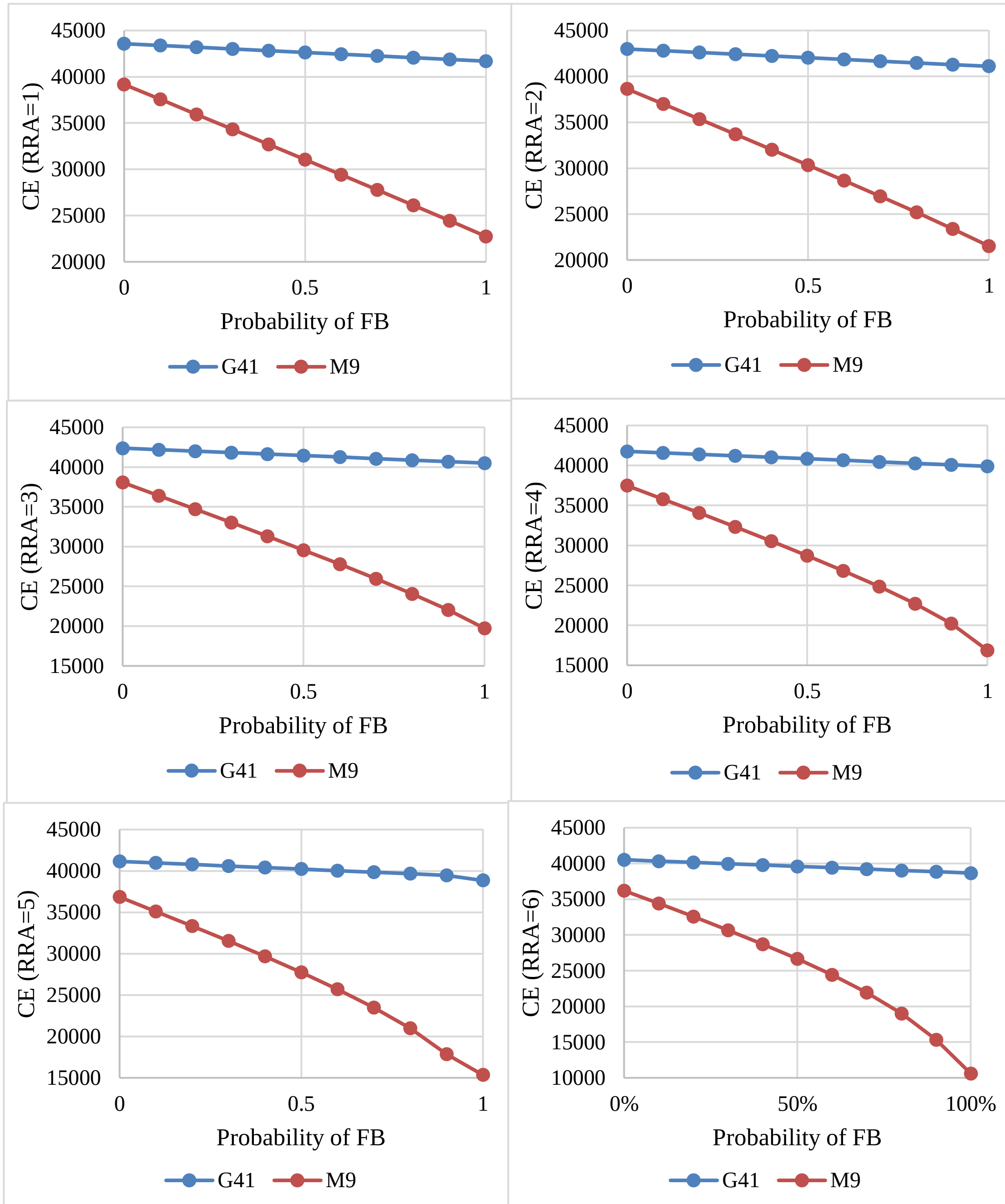

Figure 8-40 Certainty Equivalent under Different CRRA for Fuji, VA System, Dressel Farm for Different Probability of Fire Blight

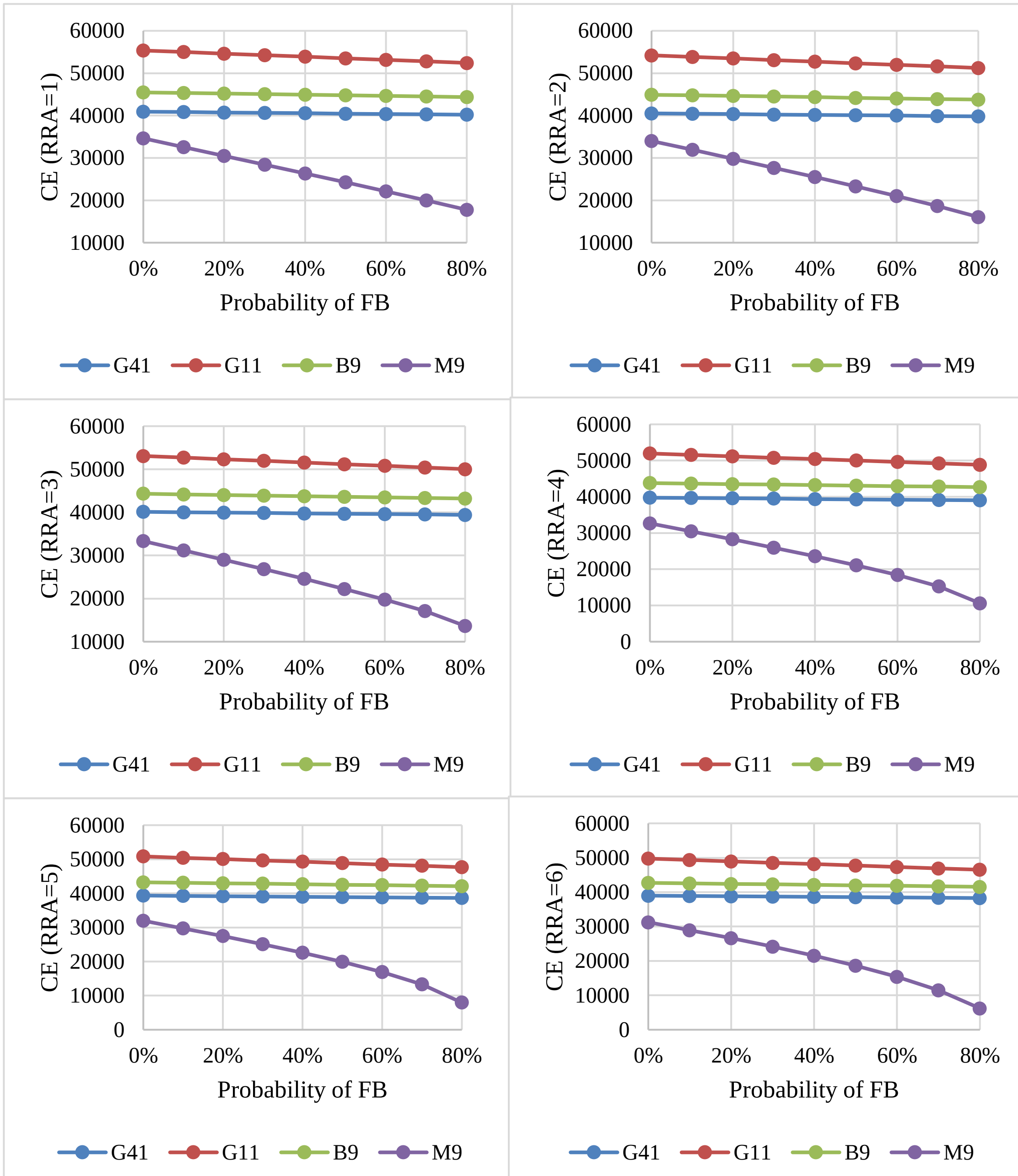

Figure 8-41 Certainty Equivalent under Different CRRA for Gala, SA System, Dressel Farm for Different Probability of Fire Blight

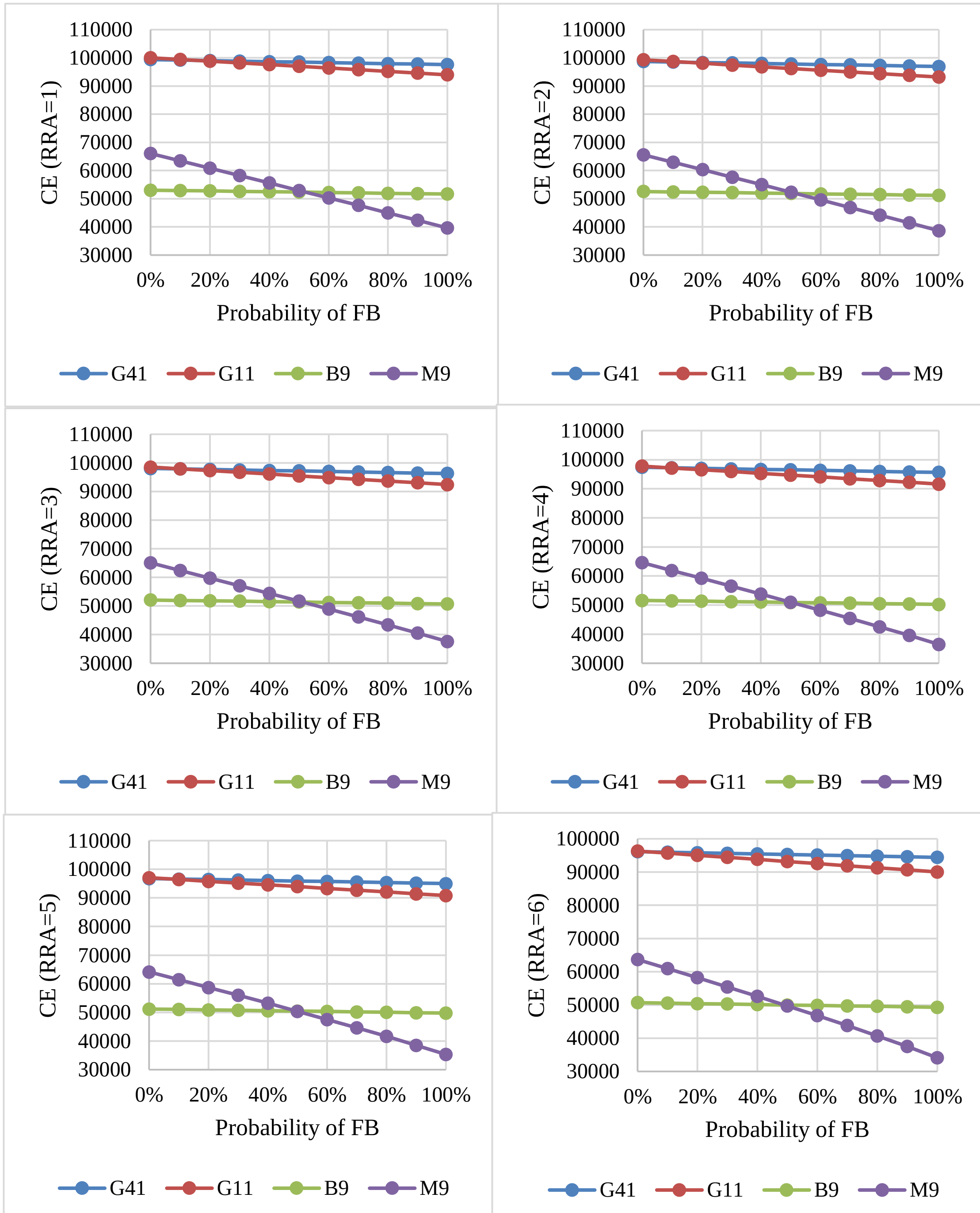

Figure 8-42 Certainty Equivalent under Different CRRA for Gala, TS System, Dressel Farm for Different Probability of Fire Blight

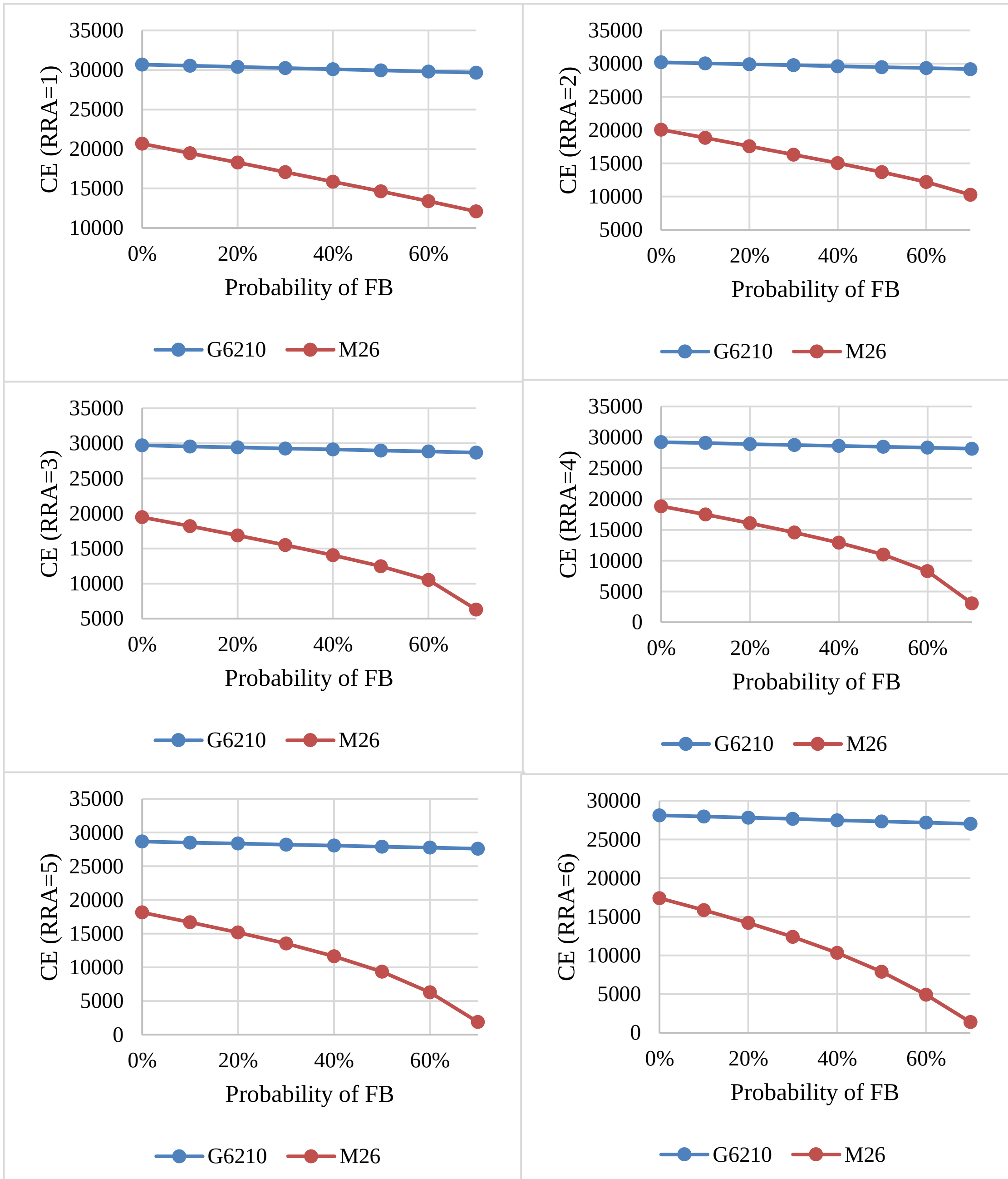

Figure 8-43 Certainty Equivalent under Different CRRA for Gala, SP System, Dressel Farm for Different Probability of Fire Blight

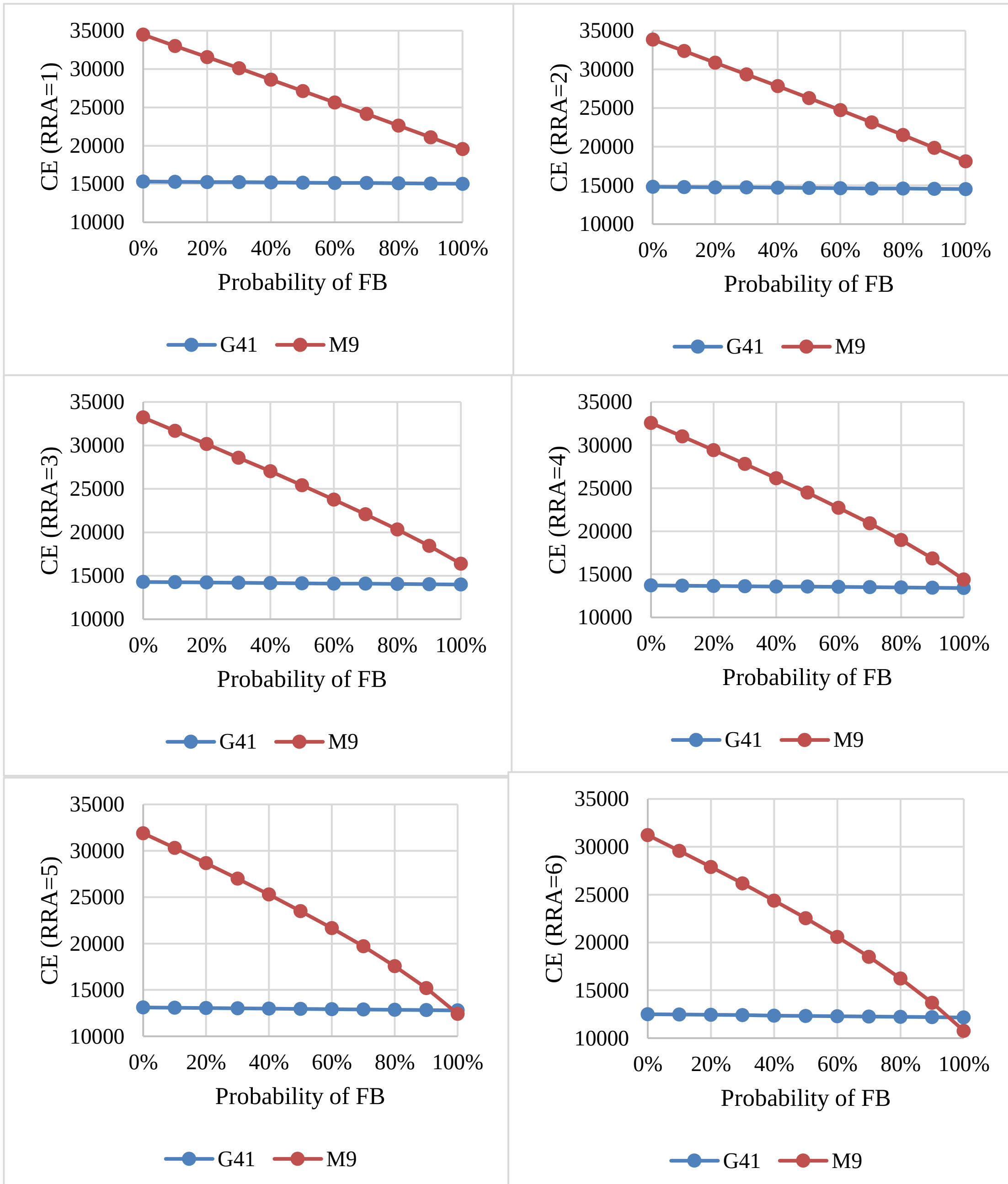

Figure 8-44 Certainty Equivalent under Different CRRA for Gala, VA System, Dressel Farm for Different Probability of Fire Blight

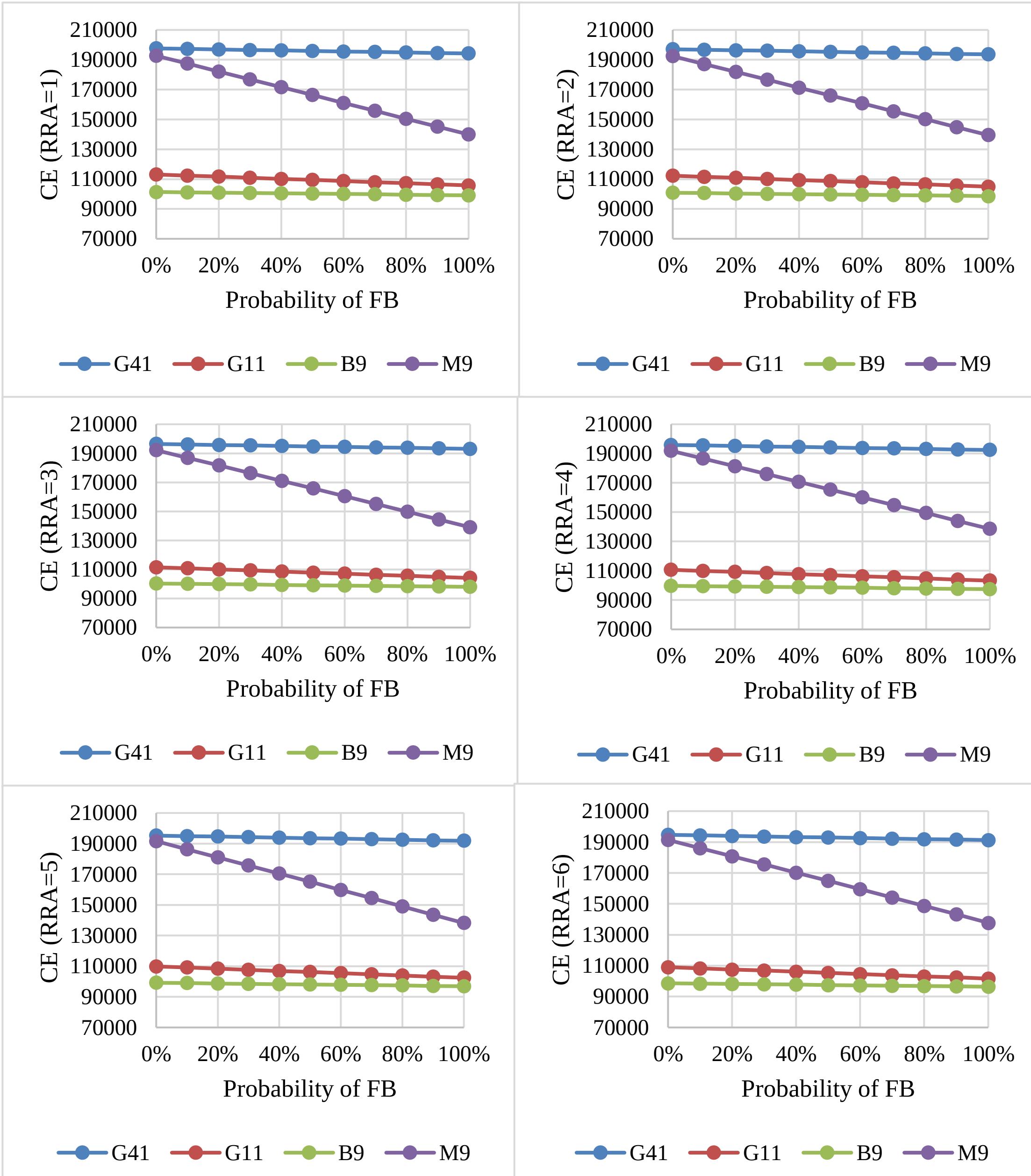

Figure 8-45 Certainty Equivalent under Different CRRA for Gala, SA System, VandeWalle Farm for Different Probability of Fire Blight

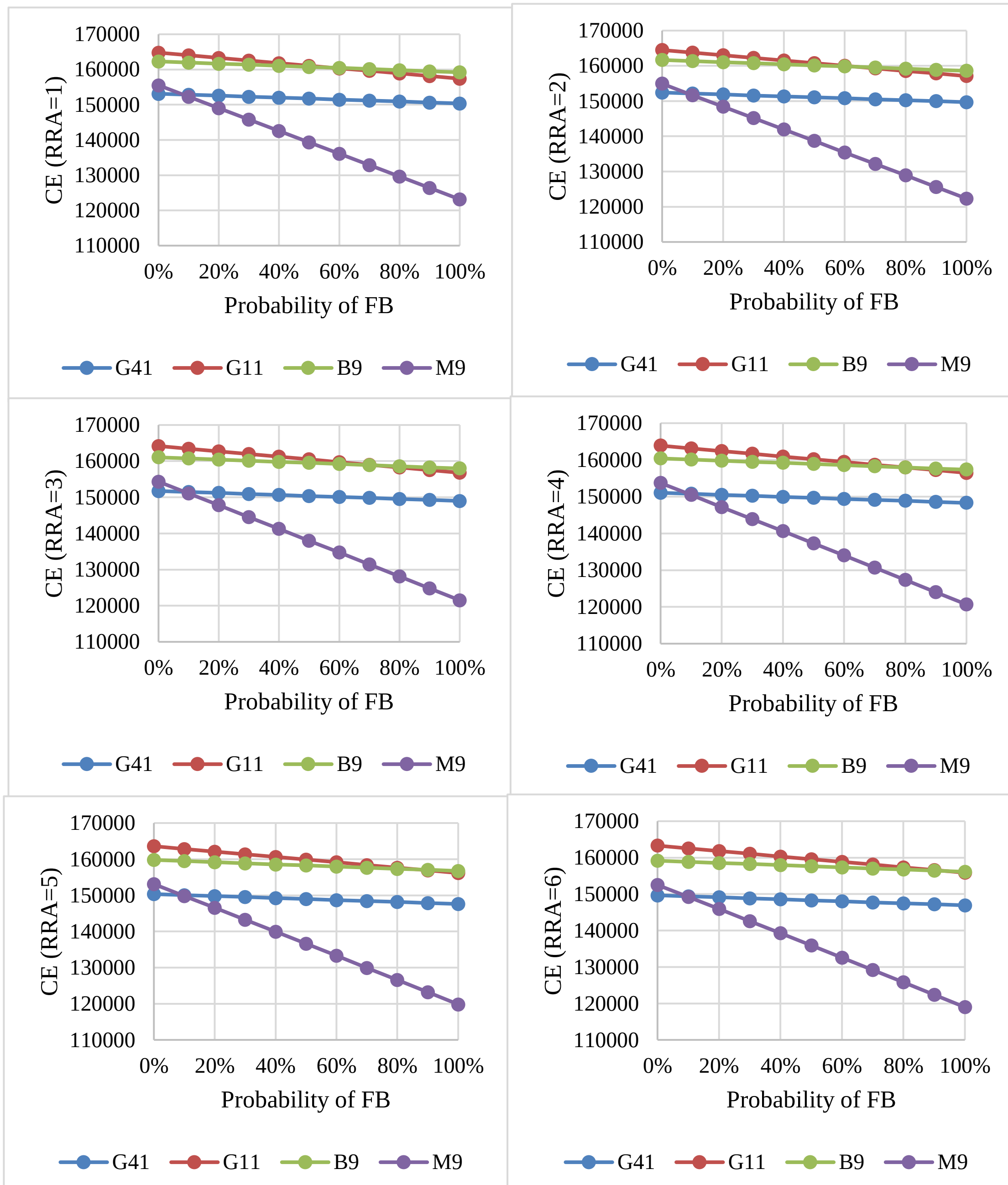

Figure 8-46 Certainty Equivalent under Different CRRA for Gala, TS System, VandeWalle Farm for Different Probability of Fire Blight

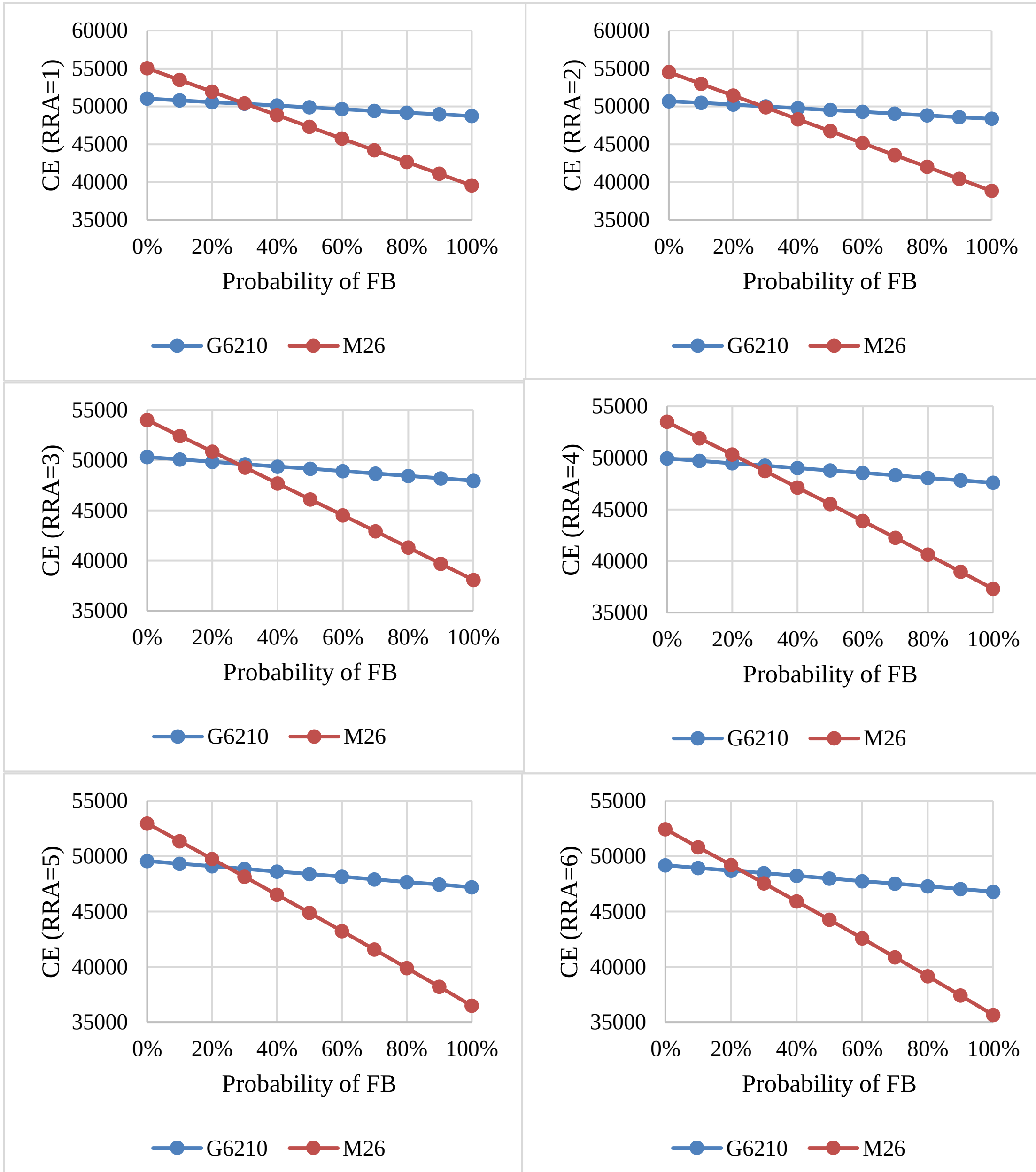

Figure 8-47 Certainty Equivalent under Different CRRA for Gala, SP System, VandeWalle Farm for Different Probability of Fire Blight

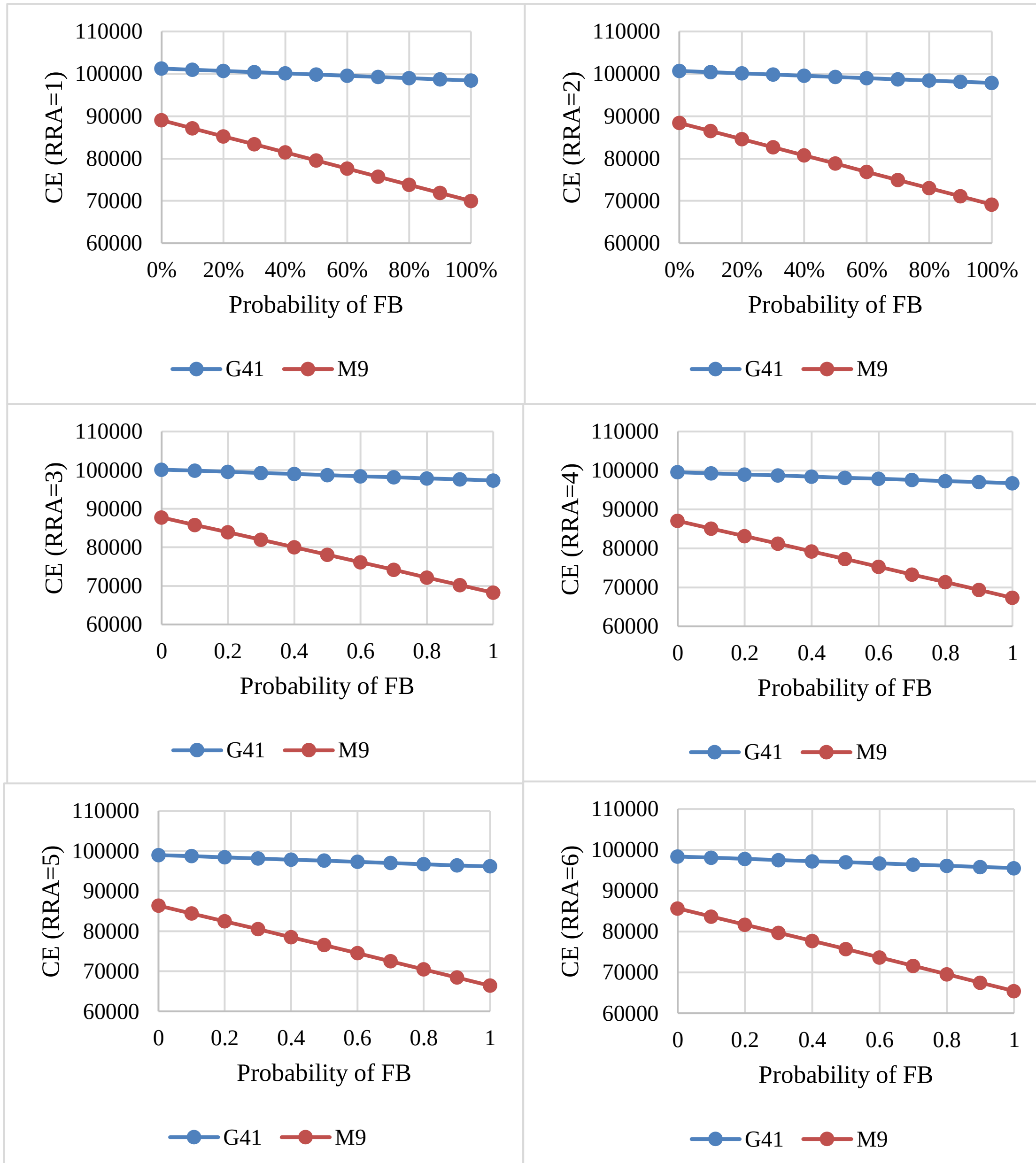

Figure 8-48 Certainty Equivalent under Different CRRA for Gala, VA System, VandeWalle Farm for Different Probability of Fire Blight